FINAL REPORT
FOR
COLOR TELEVISION STUDY

(November 1965 to March 1966)

Contract No. NAS 9-5342

Prepared by

Astro-Electronics Division
Defense Electronic Products
Radio Corporation of America
Princeton, New Jersey

for

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

PREFACE

This document covers the work performed in a four-month study program for the National Aeronautics and Space Administration Manned Space Center (NASA/MSC) by the Astro-Electronics Division (AED) of the Radio Corporation of America under Contract NAS 9-5342.

The objective of this study was to determine the optimum means of generating and transmitting color television from earth orbit and the moon.

Report Prepared By:

A. Bedford, RCA Laboratories

J. Bingley

J. Broderick

J. Kara

R. Kell, RCA Laboratories

S. Krieger

J. Lowrance

L. Saxton

A. Schroeder, RCA Laboratories

Report Approved By:

John L. Lowrance, Engineering Leader
Spacecraft Electronics, TV Cameras

Max Mesner, Engineering Manager
Spacecraft Electronics, TV Cameras

AED R-2907 Issued: March 31, 1966

SUMMARY

A study has been completed to determine the best method of originating and transmitting real-time color television from:

1. Earth-orbit to earth (less than 300 nm), including consideration of utilizing communication satellites for relay purposes.
2. Lunar-orbit to earth (S-band).
3. Lunar-surface to earth (S-band).

A major study constraint required that the video output of the ground based system conform to the NTSC* color standards so that the video could be distributed and monitored by standard color television broadcast equipment, and also be fed directly into a television broadcast network for inclusion in color television programs. The missions considered by the study were:

1. Gemini-Agena
2. Apollo Block II
3. LEM-Lunar Surface
4. Apollo Applications

The study resulted in the invention by RCA of a variable-line sequential scanning system that is the optimum method of originating and transmitting real-time color television " motion pictures " for the subject missions. The system utilizes three camera tubes and offers the potential of subsequent development of a camera system using only a single tube. The proposed line sequential system requires a 1.25-Mc video bandwidth and provides a 7.5-frame-per-second picture with 320 TV line horizontal and 350 TV line vertical resolution.

To provide high-resolution (1000 TV lines) "snap-shot" type pictures (pictures of frozen motion), the optimum choice was determined to be the proposed line sequential camera with a shutter, and operated at a slow scan rate.

To provide high-resolution color " stills" , where there is no relative motion between camera and scene or action in the scene, the optimum choice was determined to be the classical frame-sequential, single-image tube camera operating at slow scan with a filter wheel.

*National Television System Committee. The standards were adopted by the Federal Communications Commission for Commercial Color Television Broadcasting.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Section | Page

TABLE OF CONTENTS (Continued)

Section | Page

TABLE OF CONTENTS (Continued)

Section | Page

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

SECTION I

INTRODUCTION

A. PURPOSE OF STUDY

The study was performed for the NASA Manned Spacecraft Center to determine the best method of originating and transmitting real time color television motion pictures from:

(1) Earth-orbit to earth (less than 300 nm). In this case the study considered utilizing communication satellites for relay purposes.

(2) Lunar-orbit to earth (S-band).

(3) Lunar-surface to earth (S-band).

One of the requirements was to ensure that the video output of the ground based system conform to the NTSC* color standards. In this way the video could be distributed and monitored by standard color television broadcast equipment, and also be fed directly into a television broadcast network for inclusion in color television programs. The missions considered by the study were:

(1) Gemini-Agena

(2) Apollo Block II

(3) LEM-Lunar Surface

(4) Apollo Applications

In addition to real time motion pictures, the study has also considered the requirements for color "snapshots" and color "stills". "Snapshots" are defined as pictures where there is fast action in the scene or where there is relatively rapid motion between the camera and the scene; and "stills" are defined as pictures where there is relatively little motion between the camera and the scene.

---

* National Television System Committee, color standards adopted by Federal Communication Commission for commercial television broadcast.

B. STUDY PHILOSOPHY

The development of commercial monochrome television has had as a primary design constraint the requirement to make an economical and reasonably simple receiver. Commercial color television was required to be compatible with the existing monochrome receivers and remain within the 6-Mc bandwidth allocated for monochrome television.

In the study of color television systems for space applications, the design criteria are considerably different from those applied to commercial systems. In space-television systems, the emphasis is placed on simplification and miniaturization of the picture transmitting system, while the receiver and ground processing equipment may be relatively complex in comparison. Compatibility in this case is restricted to producing a picture at the transmitter which can be scan-converted to the National Television System Committee (NTSC) color format at the ground station.

The common constraint to both applications is bandwidth; in the first case by allocation, and in the second case because of the associated transmitter power and weight which, in space applications, must be accommodated on the spacecraft or lunar base station.

Another basic difference in the design criteria applied to commercial television systems and a system for use in space is the shift in emphasis on reliability from the receiver to the picture sensing and transmitting system where maintenance and adjustment is impractical.

An important aspect of the study program was to examine the various methods for achieving a color television system and establishing new sets of design criteria for the space environment.

C. STUDY GUIDE LINES

The study Statement of Work established the following guide lines and requirements.

- The signal-to-noise ratio should be adequate for achieving commercial quality pictures.
- The final ground video shall be in a form capable of being distributed in the NTSC color format.
- The real-time transmission should have minimal motion breakup.

- The system must provide a minimum horizontal and vertical, black and white resolution of 300 TV lines.
- The transmission must be constrained to a maximum video bandwidth of 6 Mc.

The Work Statement also established the following minimum number of criteria to be considered in determining the best system.

- The rapidity and case of obtaining the proposed system, where the maximum development period to produce operating flight-type hardware shall be nominally considered 2 years.
- The equipment's past flight qualification history.
- The study also had to consider the overall system in terms of power, weight, size, resolution, bandwidth, grayscales, color rendition, and other picture quality parameters.
- The cost of developing a suitable system.

Furthermore the equipment to be recommended has to endure environmental conditions of:

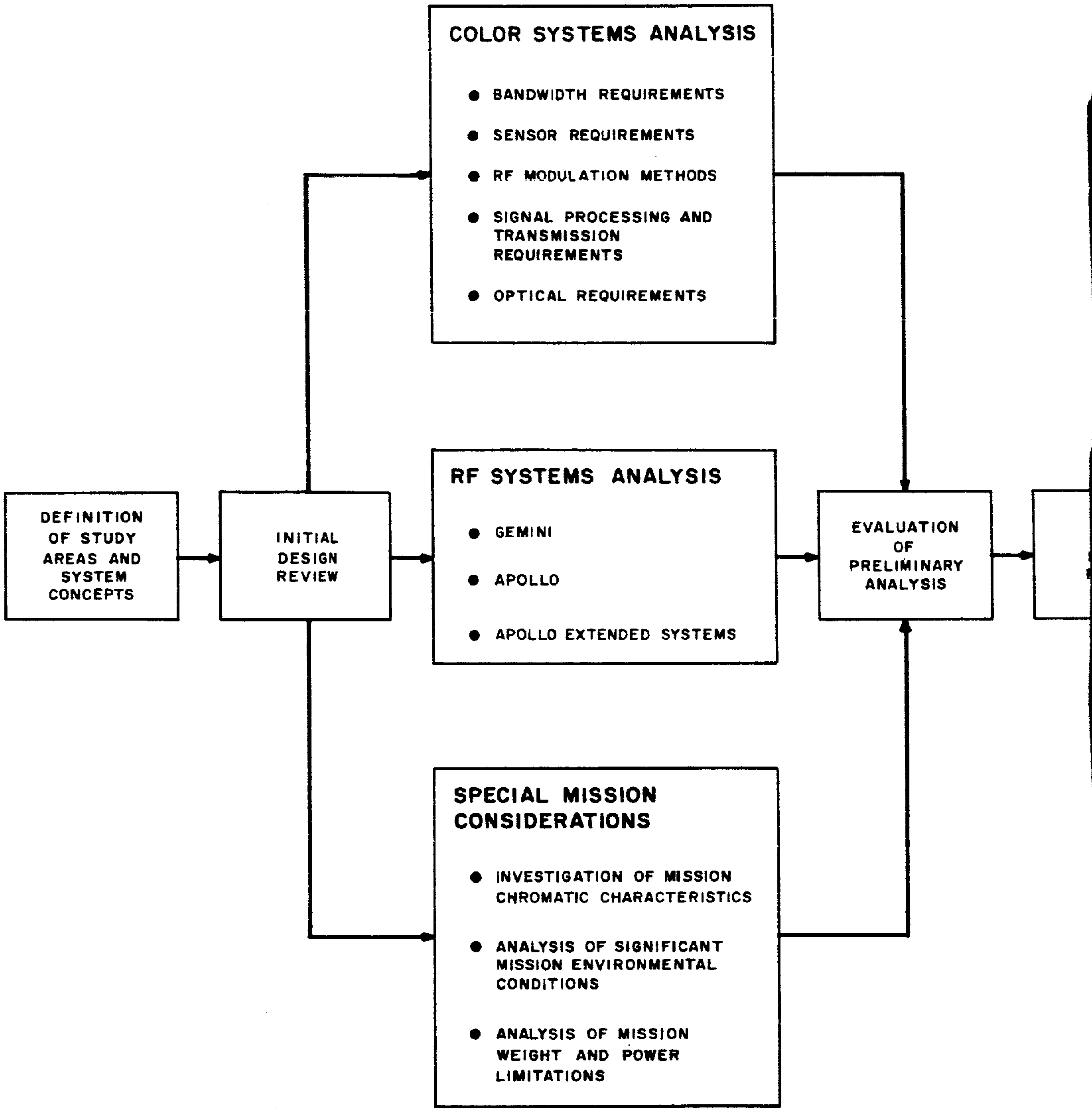
- Ground shipment and operation
- Ascent and descent from the earth or lunar surface (equipment non-operating)
- Earth-orbit cabin operation
- Earth-orbit operation external to cabin
- Lunar-orbit cabin operation
- Lunar-orbit operation external to cabin
- Lunar-surface operation

Early in the study, it became obvious that any application of color television to the near future manned space missions would have to rely on existing ground stations and Apollo-LEM communication equipment. Concurrently, it also became necessary to pick a video bandwidth that could be used in tradeoff analysis of the various color television systems under consideration. Thus, 1.25 Mc was selected as the most suitable video bandwidth. This choice was based on the fact that (1) the existing Apollo and LEM video transmitters had a bandwidth of 1.25 Mc, and (2) the bandwidth was consistent with the resolution and minimal motion breakup requirements of the Statement of Work.

D. STUDY ORGANIZATION

The study flow diagram shown in Figure 1 illustrates the way in which the study was conducted. It graphically shows the process employed in arriving at the optimum system for originating and transmitting real-time color television. from space. The three design reviews (Initial Review, Major Review, and Final Review) were an important part of the study program.

The study program was fortunate in having the services of men who were key contributors to the development of commercial color television as well as men who are closely associated with space hardware requirements and space television applications. The Design Review Board included members of the technical staff from AED as well as other divisions of RCA. The Initial Review served to acquaint all participants with the study objectives and ground rules. It also resulted in recommendations regarding the course the study should take. The Major Design Review served as a forum for discussing the conclusions of the general analysis. Approval of these conclusions then led to the detailed system analysis and specifications for the various missions. The Final Review served as an approval by the Technical Staff of the proposed systems and overall study.


COLOR SYSTEMS ANALYSIS
BANDWIDTH REQUIREMENTS
SENSOR REQUIREMENTS
RF MODULATION METHODS
SIGNAL PROCESSING AND TRANSMISSION REQUIREMENTS
OPTICAL REQUIREMENTS
DEFINITION OF STUDY AREAS AND SYSTEM CONCEPTS
INITIAL DESIGN REVIEW
RF SYSTEMS ANALYSIS
GEMINI
APOLLO
APOLLO EXTENDED SYSTEMS
EVALUATION OF PRELIMINARY ANALYSIS
SPECIAL MISSION CONSIDERATIONS
INVESTIGATION OF MISSION CHROMATIC CHARACTERISTICS
ANALYSIS OF SIGNIFICANT MISSION ENVIRONMENTAL CONDITIONS
ANALYSIS OF MISSION WEIGHT AND POWER LIMITATIONS

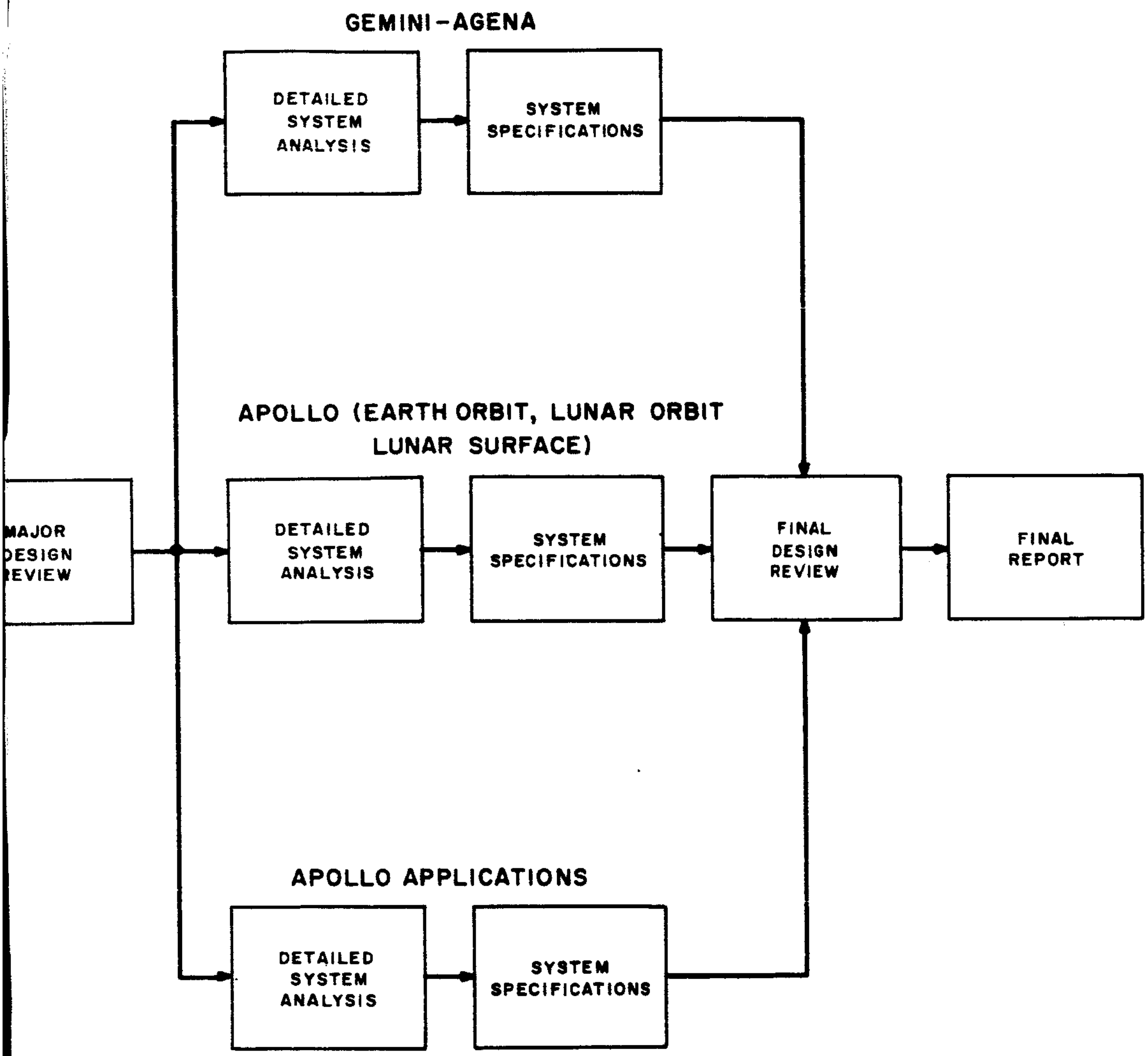


Figure 1. Color TV Study, Flow Diagram

2

SECTION II
GENERAL COLOR TELEVISION SYSTEM ANALYSIS AND DEVELOPMENT

A. COLOR IMAGING SYSTEM STUDY

1. Introduction

In seeking a system of color television that would be appropriate for use in a space application, it is of value to review the approaches considered in developing the system for broadcast color television. The history and principles of these approaches are briefly discussed in this introduction. Many practical differences exist between the requirements and constraints of broadcast service and space operation. Some of these factors, which must be considered in designing a practical color television for operation in space, are as follows:

(1) The requirement for scan conversion from space standards to broadcast standards;

(2) The lower baseband available for most space missions;

(3) The lower frame rate that must be used in space to obtain pictures with resolution equal to broadcast television; and

(4) The difficulty of in-spacecraft adjustment of the color separation images in the camera.

All systems of color television depend broadly upon the division of the visible spectrum into three bands of color (red, green, and blue) and the generation of three video signals, each representing one of the three colors and the amount of that color contained in a given area of the original scene. Usually the video signals (often called "color separation signals") are normalized so as to be equal for white areas. In the television receiver, these separation signals may be used to control the light outputs of three phosphors which fluoresce in red, green, and blue colors, respectively. The phosphors may be deposited on three separate picture tubes, which are suitably scanned in synchronism with the scanning at the camera. One tube displays the red image, another the green image, and the third tube displays the blue image. These images are then superimposed in register by means of an optical system; whereupon the original scene is recreated as a colored image. Such a system of color reproduction is called "additive" the red, green, and blue images are added to produce the colored image.

The three color-fluorescing phosphors may be placed on the screen of a single color display tube, sharing the screen area in the form of an array of dots (a total of about one million) in groups of three (one of each color) placed upon the screen by a printing process. In this system, three electron guns are placed close together in the neck of the tube, and each gun is used to control one of the colors. A perforated mask (called a "shadow mask") placed close to the phosphor screen ensures that the beam from the "red" gun can only reach the red phosphor dots, and performs a similar function for the "green" and "blue" guns. The shadow mask has one hole for each triplet of color dots; parallax between the three guns, due to their slight displacement one from the other, causes their respective electron beams to diverge while traveling the short distance between the mask and the screen. The divergence is such that each beam impinges on the screen in the area bearing the appropriate color phosphor dot. This type of color display tube is used in essentially all broadcast color television receivers. It obviates the necessity of optical superposition of the images.

In setting up a standard color television system suitable for broadcast service, several possible systems were considered together with their relation to the constraints existing at the time. Among the constraints were:

(1) The limited number of television broadcast channels available in the VHF band;

(2) The current existence of monochrome service and of a large number of monochrome receivers in the hands of the public; and

(3) The investment of the television broadcasters in plants and facilities.

These constraints all indicated the importance of at least some measure of compatibility of the color broadcasts with the existing monochrome receivers and the broadcasting plants. It was considered by most authorities that the existing 6-megacycle channel width should be preserved to avoid a reduction in the number of available VHF channels. This bandwidth constraint imposed a problem because part of the band was required for the transmission of the color information. One solution considered was the use of a lower frame rate. (The monochrome standards specify a frame rate of 30 frames per second and a flicker frequency of 60 cps.) However, if the flicker frequency is reduced below 48 cps, the flicker becomes objectionable to the viewer. Another method considered for coping with the bandwidth constraint was the use of lower resolution instead of a lower frame rate. A modification of this method was the use of a combination of lower resolution and lower frame rate.

Two ideas thought of early during the search for a standard color television system for broadcasting were the field sequential and the line sequential systems. These two systems were later supplemented by a third; the dot sequential system, a form of which was subsequently adopted as the standard and is presently in use.

The field sequential system employed time-sharing among the red, green, and blue video separation signals. It employed interlaced scanning which raised the flicker frequency by a factor of two. In interlaced scanning, the frame area is scanned twice; the first scan covers the odd-numbered lines in the frame, and the second scan covers the alternate lines, which were left by the first scan. Higher orders of interlace (for example, 3 to 1 or 4 to 1) are possible but are unsatisfactory due to the presence of stroboscopically-traveling lines. The 2-to-1 interlace was already in use for monochrome television, and its benefits (and the problems of higher order interlace) were well established. The monochrome system used 60 fields per second (a field is the group of odd- or even-numbered lines covered in a scan) which provided 30 frames per second (a frame is the aggregate of the two fields and thus contains all of the scanning lines). The field sequential color system had a reduced field rate of 48 fields per second (flicker frequency of 48 cps) to help offset the loss of resolution due to the sharing of transmittable resolution elements by the red, green, and blue fields. The number of scan lines per frame was 405 as opposed to 525 for the monochrome system.

In operation, the field sequential system transmitted a red field for 1/48 second, covering $202\frac{1}{2}$ lines (one field consisting of every other line of the 405-line picture). A red filter was interposed in front of the camera tube during this field; thus, the output of the camera for this period was the red separation video signal. The red filter was then replaced by a green filter and, in turn, by a blue filter, generating the green and blue separation signals, respectively. The process was then repeated in the same order, scanning the alternate lines in the interlace pattern for each color. The scanning of the six fields was done in 1/8 second, and covered two fields for each color (red, green, and blue). The substitution of color filters was accomplished by mounting the filters on a wheel whose rotation was synchronized to the vertical scanning rate.

The field sequential system had several disadvantages. The margin of flicker threshold in this system was considerably less than that contained in the monochrome system, and later improvements in display brightness crossed this flicker threshold and resulted in perceptible flicker. The image resolution had been degraded by the reduction from 525 to 405 lines, and degraded further by the reduction of resolution along each scanning line due to the bandwidth limitation. Another disadvantage of this system was its incompatibility with existing monochrome receivers. In order to obtain a monochrome rendition of a color broadcast, it would have been necessary to change the receiver deflection and to add hum filtering. Moreover, as a system limitation, color fringing occurred on rapidly moving objects.

In the line sequential system, each camera scanning line was divided into three segments, each segment allotted to the generation of the video signal corresponding to one of the color separations. The three color-separation images of the scene were placed side by side on the target of the camera tube, and each was scanned in turn during each pass of the scanning spot. The horizontal scanning was arranged to cover each color segment in the same time as that taken to cover a complete line in the standard monochrome system. The vertical deflection rate was 60 cps, and 2-to-1 interlace was used. Thus, the scanning standards were similar to those of the monochrome system. Although the horizontal resolution was equal to that obtained in the monochrome system, the vertical resolution was only one third. This reduction was the result of sharing the available bandwidth equally among the red, green, and blue fields. Furthermore, the color transmission exhibited objectionable line crawl when viewed on a monochrome receiver. This effect occurred because the luminance values of consecutive scanning lines (representing red, green, and blue) were not equal. The regular cyclic variation caused an apparent crawl or motion of the scanning lines due to the stroboscopic effect. The objectionable line crawl, combined with the loss of vertical resolution in all three of the separation images, was sufficient cause to remove this system from consideration.

Historically, the dot sequential system was the next to receive attention. In this system, a set of three video color separation signals were generated simultaneously. Each separation signal conformed to the scanning standards in use for monochrome television broadcasting. These signals were sampled sequentially at a rate of approximately 4 megacycles per second. The sampling intervals on successive lines were displaced by an amount equal to one-half the distance between consecutive samples along one line. This method of sampling increased the effective frame time to 1/15 second (compared to 1/30 second for monochrome broadcasting) and doubled the number of transmittable elements per frame. The additional elements per frame partially compensated for the necessity of sharing transmittable elements among the three separation pictures.

In the course of development of the dot sequential system, it became apparent that the signal generated by the sampling process consisted of a monochrome signal and a subcarrier, and that the subcarrier vanished when white was transmitted. It then became obvious that the sampling technique used was a special case of a more general category, and that there were other methods of generating a subcarrier that would vanish on white. There were also many suitable signals that could be utilized for the monochrome component. The realization of these principles lead to the optimization of the dot sequential system. Further investigation revealed that less objectionable interference resulted if the subcarrier did not control display luminance, and that color fidelity of the display could be achieved by using a monochrome signal that was proportional to luminance. The subcarrier became known as the "chrominance subcarrier" (or more briefly, as "chrominance") by analogy with the term "luminance." The complete color video signal was thus composed of two components -- the monochrome luminance signal and the chrominance signal. The former controlled only the luminance of the display; the latter controlled the color of the display. Later development was directed toward the inclusion of gamma correction in the video signal. This application violated somewhat the clear division of control possessed by luminance and chrominance.

Development of the dot sequential system from the original concept to the system in use today was accomplished by the National Television System Committee (NTSC). The system became known as the NTSC system, and was proposed to the Federal Communications Commission for adoption as the color television broadcasting standard. The NTSC system was completely compatible with the existing monochrome system. The scanning standards were identical, and color broadcasts to these standards could be received (in monochrome) by existing monochrome television receivers without modification. After public hearings, the FCC selected the NTSC system as the standard for color broadcasting.

2. NTSC Color Television System

The study to determine the optimum distribution of color picture information in any communication channel has as a logical starting point the present NTSC color television system. This system has as its background hundreds of hours of tests in many laboratories. The final decisions as to the balancing of the various factors involved was based on the judgment of the engineers of the entire television industry. The soundness of these decisions is reflected today in the booming color television industry. Since color pictures are made up of three (red, green, and blue) separate pictures, it could be logically concluded that the communication channel would have to be three times as wide as for monochrome television.

The characteristics chosen for the NTSC color system made possible the transmission of a color picture having the same subjective detail as that of present monochrome, and in the same available frequency spectrum. The principles of the NTSC color system will be applied where feasible to the transmission of color television from outer space.

The required modifications of an NTSC type signal to meet the special requirements of this application will be more readily understood after a review of the basic principles of the NTSC system.

Before discussing the subtle subjective and objective aspects of the unique multiplex features of the NTSC system, the pertinent physical standards will now be presented.

As shown in Figure 2, the picture carrier (corresponding to zero video frequency) is located 1.25 Mc above the lower end of the 6-Mc r-f band assigned by the FCC to a single television station. The luminance signal, Y, transmitted by the amplitude-modulated picture carrier with vestigial lower sideband is the same as for monochrome transmission and must be essentially zero at 4.5-Mc video in order to accommodate the frequency-modulated sound carrier, which is located 4.5 Mc above the picture carrier.

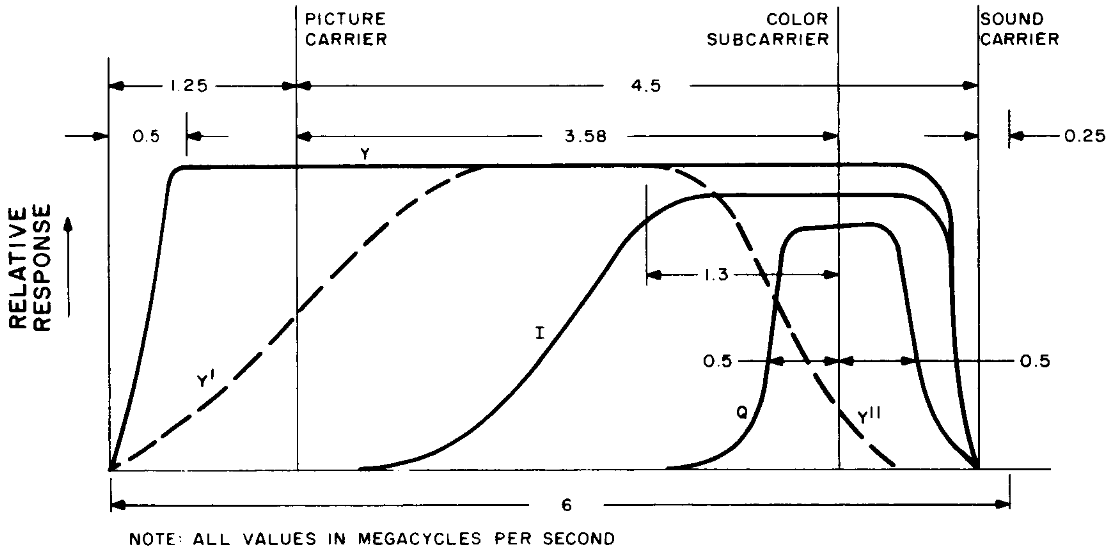


Figure 2. Frequency Spectrum, NTSC System

The color information is carried on a single 3.58-Mc subcarrier which is composed of two signals at quadrature (90 degrees apart), each modulated by a video signal, I and Q respectively. The two pairs of sidebands indicated in the figure as I and Q, overlap the luminance band. This dual use of the same band for information transmission is not generally considered a legitimate form of multiplexing. However, in the present case, it is acceptably free from cross-talk because of several unique subjective and geometric relations.

Tests* with human observers have shown that the visual acuity for detail residing in differences in luminance is several times as great as the acuity for detail residing in differences in color only. This condition is illustrated roughly by the fact that small red letters on a green background of equal brightness cannot be read as easily as white letters on a black background.

The "mixed highs" technique is used to save bandwidth by taking advantage of this deficiency of vision. This method consists of transmitting only that low-frequency video color information which is required to allow the reconstruction of the separate red, green, and blue images with relatively coarse picture detail. The luminance information of the three color images remains "mixed" together so far as the high-frequency fine detail is concerned. The resulting narrowness of the I and Q sidebands relative to the luminance reduces the cross-talk problems as will be evident later.

The reproduction of a color picture in the receiver requires the use of three independent signals (R, G, and B) to drive the red, green, and blue guns of the kinescope. The luminance signal Y is the sum of the R, G, and B signals with suitable factors to take account of the fact that the green component of white light has the greatest luminance and the blue component the least in this ratio:

$$Y = 0.59G + 0.30R + 0.11B \qquad (1)$$

If the color subcarrier is made to transmit any two of the R, G, and B signals, such as R and B, the third one can be obtained by using a simple matrix circuit in the receiver. (This matrix can be solved for G by analog additions and subtractions, when Y, R, and B are known.) Alternatively, if the difference signals (R-Y) and (B-Y) are transmitted, it is similarly possible to reconstruct (G-Y).

The two 90-degree components of the color subcarrier can be readily separated from one another at the receiver by synchronous detection, using the reference signal produced from the color sync burst transmitted during horizontal blanking. Therefore, the color subcarrier can be made to carry R and B, or (R-Y) and (B-Y), or some other pair.

For good reason the actual modulating signals are I and Q, each of which is a different combination of the R, G, and B signals (or difference signals) as follows:

$$I = -0.274G + 0.596R - 0.322B \qquad (2)$$

$$= 0.735\,(R-Y) - 0.269\,(B-Y) \qquad (3)$$

$$Q = -0.522G + 0.211R + 0.311B \qquad (4)$$

$$= 0.477\,(R-Y) + 0.414\,(B-Y) \qquad (5)$$

*A.V. Bedford, "Mixed Highs in Color Television," Proc. IRE, Sept. 1950.

A consideration of equations (2) and (4) indicates that the color signals R, G, and B could be obtained from I, Q, and Y. However, in most color receivers, the signals (R-Y), (B-Y), and (G-Y) are obtained as suggested by equations (3) and (5); these so-called color-difference signals are applied to the three grids of the three-color Kinescope while the luminance signal Y is applied to the three cathodes. In accordance with the "constant luminance" technique, the coefficients of the R, G, and B signal components in I and Q have been chosen so that random noise in the color carrier channel will produce substantially equal visible effects in each of the R, G, and B channels, but will produce no luminance noise.

There is another feature derived in transmitting the color-difference signals on the two 90-degree orthogonal components of the color subcarrier. That is, the color subcarrier reaching the receiver can be synchronously detected at any angle out of the 360 electrical degrees to obtain the color-difference signal (C-Y), where C represents any one of the infinite hues (including R, G, and B) in the classical color circle. Such detecting is in effect a form of matrix and may allow economies in receiver design.

A further result of the color transmission system is that the amplitude of the net color carrier with respect to the luminance signal at any instant is proportional to the color saturation (or chroma), and the relative phase of the color carrier directly indicates the hue. Thus, the color carrier is automatically zero except in picture areas which have color, i.e., other than black, white, and gray. This feature minimizes visibility of any residual color carrier dots on a statistical basis. However, the system is vulnerable to any phase infidelity of the subcarrier transmission.

The reason for the transmitting of the I signal with a wider bandwidth than that for transmitting the Q signal is an extension of the general philosophy of "mixed highs". Inspection of equation (2), which gives the composition of the I signal, shows that I swings toward the positive for an increase in R and toward the negative for an increase in G or B. Likewise, inspection of equation (4) shows that Q swings positive for an increase in R or B and negative for an increase in G. The assignment of the narrowband Q signal to produce color changes from purple (that is R and B) to green is the result of many tests which indicate that the eye has less acuity for detail residing in the colors from purple to green than for detail residing in the colors from red to blue-green. All colors are kept at equal luminance since the signals I and Q do not change the luminance, which is transmitted only by Y.

So far it has been explained why the relatively narrow I and Q bands are adequate to carry the necessary color information. It remains to show how the I and Q signals are transmitted with their own sidebands partly superimposed upon each other and upon the luminance band, with tolerable two-way interference between color and luminance information.

The key technique was to make the color subcarrier frequency equal to an odd multiple of one-half the picture line frequency. When this technique is used, the residual dots produced by the color subcarrier in any one line occupy interlaced positions on alternate scannings of that line. As used in current receivers, this relation is known as "dot interlace" or "frequency interlace". It is effective because the color subcarrier and sidebands which produce dots or other luminance crosstalk produce the opposite effects on the next scan. Cancellation thus occurs to the extent that the effects are integrated over two frames (neglecting the great non-linearities of the system, residing mostly in the "gamma" of the color kinescope). Similarly, where the luminance signal, Y, operates in the receiver color circuits to produce color crosstalk, the false color effects are nominally cancelled in the summing of two frames. If this process were perfect, the simultaneous multiplexing of different signals in the same band would be accomplished without crosstalk because the price for apparent bandwidth economy would have been paid by the reduction of the whole-picture repetition to 15 frames per second.

Because of inadequate retentivity of the human eye, the attention of the observer sometimes travels with dots that move, in the same sense that sequential flashing lamps in a theater sign appear to move. Then the pattern of the dots "crawls". Fortunately, this condition of subjective crosstalk is also cancelled to a great degree by dot interlace. After one line has been scanned producing a certain crosstalk, the dot-interlace causes the crosstalk in the next line scanned (which is space-wise two line pitches away) to have the reverse polarity, if the two lines are identical in subject matter. Since most pictures have much redundancy from line to line, the resulting cancellation is quite effective in overcoming the inadequate one-fifteenth-second storage of the eye. It is of interest to note that the effectiveness of the polarity reversal of the color error in the two lines is dependent upon the same lower eye acuity for color detail which is the basis of the "mixed highs" principle; that is, only the mean of the two different colored lines is seen.

The foregoing discussion implies that each line of the picture has a high probability of being very much like its neighboring lines. This condition has been effectively verified by analyzing the frequency spectrum of the television signals produced by many television picture subjects. Typically, the amplitudes of the frequencies occurring at harmonic multiples of the line frequency have been tremendously greater than for other frequencies. If all lines were identical, only the harmonic frequencies would be generated in the luminance channel; conversely, the sidebands and carrier of the color subcarrier would be void of components at the line harmonic frequencies.

In the frequency response diagram of Figure 2, the transmitted luminance signal Y is shown extending to 4.2 Mc, whereas the response of the luminance signal Y in the receiver is greatly reduced before the color subcarrier at 3.58 Mc. This design substantially removes the color subcarrier, and has proved effective for removing spurious dots in the receiver because the subcarrier amplitude is generally greater than that of its sidebands. The reason for this is that in typical pictures a given color statistically tends to be continued along the line, thereby generating frequencies very near the subcarrier.

The design of the transmitted color signal with a narrower band for Q than for I was originally based on the use of receivers with separate I and Q circuits having different bandwidths. Thus the Q channel would have been spared the crosstalk from the luminance and from the I signals beyond the narrow transmitted Q sidebands. Actually, for reasons of economy, almost all present commercial color receivers use the same bandwidth (having 1-Mc lower sideband) before the synchronous detectors, and these detectors operate at other angles than those which yield the I and Q signals. This compromise design does not minimize the crosstalk into the Q component of signal, but the effect of restricting the width of the Q sideband at the transmitter is still helpful in minimizing the crosstalk of Q into the I component. The compromise is commercially acceptable because the Q information is subjectively less vulnerable than the I information.

Experimental laboratory color receivers which use comb filters have been made and tested to profit further from the line-to-line redundancy of television picture subject matter.

The operation of the comb filter may be explained briefly as follows. Non-interlaced frequencies are those that have the same phase on succeeding lines (luminance detail). Interlaced frequencies are those that are exactly out of phase on succeeding lines (color information). Non-interlaced frequencies are integral multiples of line frequency, and interlaced frequencies are an odd multiple of one-half the line frequency. If the signals from two adjacent lines are added, the interlaced frequencies cancel and the non-interlaced frequencies add.

Conversely, if the signals from two adjacent lines are subtracted, the non-interlaced frequencies cancel and the interlaced frequencies add. The comb filter for selecting the luminance signal (Y) effectively adds the received signal for two or more "time-adjacent" lines (thus, if full line-to-line redundancy existed, the chrominance signal, which is interlaced, would be cancelled, leaving only the luminance signal). At the same time, the luminance signal so selected is subtracted from the received signal to obtain a chrominance (I and Q) signal which is free of the Y signal.

It should be noted that because of the interlaced scanning, the "time-adjacent" lines are really two lines apart geometrically, and hence have less redundancy. The comb filter technique would be even better if it were applied to combine the signals of geometrically adjacent lines, as would be done if sequential scanning were used.

3. Other Color Television Broadcast Systems

a. SECAM SYSTEM

The SECAM system was devised by Henri de France of Compagnie Francaise de Television. It differs from the NTSC system in the way the chrominance subcarrier is utilized. In place of the combination of phase and amplitude modulation effected by the two chrominance vectors operating in quadrature, as practiced in the NTSC system, the subcarrier is frequency modulated. The modulation of the subcarrier is switched, on alternate scanning lines, between R-Y and B-Y. Thus the vertical resolution of chrominance is reduced to one-half the value achieved with NTSC; but the requirement for transmission of a color burst, to be used at the receiver for generating a reference carrier for synchronous demodulation, is eliminated. At the receiver, the missing information is approximated by supplying prior-line information by means of a transmission line that provides a delay of one TV line, and suitable switching circuits associated with the subcarrier detector. Identification of the scanning line carrying R-Y information is required for proper synchronization of the switching, and a signal to do this is included in transmission.

The results of a demonstration before the members of the British Institution of Electrical Engineers have been reported*. The color signal, originating in Paris, was relayed to London by microwave with a short terminal section of coaxial cable; the baseband of the circuit was 5 Mc. Discussion following the demonstration indicated a noisier chrominance channel than NTSC (by 11 to 16 db). The problem of effective vertical misregistry was discussed, as well as the disadvantage of the lower vertical resolution with no offsetting advantage of greater horizontal resolution. The problem of white balance was brought up, with some inference that the system was inferior to NTSC. The continuous presence of the subcarrier in white areas was noted.

---

* R. Chaste and P. Cassagne "Henri de France Colour Television System" Proc. I.E.E. (London) April, 1960, Paper #3251E

A later paper discussed the colorimetry of SECAM* and concluded that it was satisfactory. It was pointed out that SECAM has an advantage in being somewhat less sensitive to differential gain and phase than NTSC.

So far as has been determined, no report of broadcast experience has been given. It is anticipated that, where multipath conditions exist (often the case with a broadcast service), their effect would be severely detrimental. Experience obtained during the series of field tests which led to the setting of monochrome television broadcast standards in the United States demonstrated conclusively that low-deviation frequency-modulation (similar to that used in SECAM for the chrominance subcarrier) was unusable in the presence of even slight multipath. It is to be expected that SECAM would suffer similar severe degradation. However, it is not anticipated that multipath will be a problem in satellite television systems, except for the periods of over-the-horizon signals, provided that the antenna system is adequately directional.

b. PAL SYSTEM

This system was proposed by Telefunken A. G. The name is an acronym derived from "Phase Alternating Line". It is very similar to NTSC, except that the color carrier phase is reversed after each scan line. Because of this reversal, any hue error generated at the receiver by misphasing of the reference carrier regenerated from the color sync burst, can be balanced out. The balancing is achieved by storing the prior scan line in a transmission line having a delay of one horizontal period. Storage is done before demodulation. The effect of color carrier phase reversal is to cause cancellation of the color reference signal phase error. In this respect, the PAL system achieves exactly the same effect as did the NTSC "Color phase alternation" (CPA), which was at one time proposed as part of the NTSC standard. However, in the NTSC proposal the phase was changed for every field. In the presence of receiver color reference error, successive fields had hue errors which resulted from equal positive and negative angular displacements of the phase angle about the true value. The alternation of color carrier phase at the transmitter caused a corresponding alternation of effective demodulation angle at the receiver. The corresponding display hue errors were integrated by the viewer's eye to restore the correct hue; however, slight differences in the luminance of two successive fields existed due to the alternating hue offsets. These differences caused 30 cycle flicker to appear. Because this flicker was found to be objectionable, the proposal to use CPA was abandoned.

---

*G. B. Townsend "Colour Performance of the Secam Colour Television System" Proc. I.E.E. (London) Volume 110, No. 8, August, 1963

No report of broadcast experiences with PAL has been found. Experience with echo-cancellation obtained during early field tests of monochrome television may supply pertinent information. This technique consisted of periodic 180-degree shifting of the phase of the transmitter carrier to cancel ghost images caused by multipath conditions. When the phase was changed after each field, 30-cycle flicker appeared in that area of the picture in which the ghost was cancelled. When the phase was changed, a stroboscopic effect was produced, and the scanning lines in the ghost area appeared to crawl. The effect was very objectionable. Similar effects of line crawl were observed with the color television system (line sequential) proposed by CTI.* It is possible that an effect of this nature may occur with the PAL system; it would only be observable in field tests of braodcast service.

4. NTSC-Type Color Television Systems for Space Applications

a. GENERAL

In the course of the study, six hypothetical systems were considered. Each system was studied to determine its suitability with respect to the system constraints, and all the systems were compared to determine which schemes had the required characteristics and the greatest potential value. The various arrangements considered are identified herein as System A, System B, etc.

The following constraints are placed on the color television system for space applications:

(1) The available bandwidth for color television transmission is limited to 1.25 Mc;

(2) The received signal must be convertible to the standard NTSC color signal at the ground station; and

(3) The picture resolution must be comparable with present NTSC color transmission.

In addition to these constraints, other desirable characteristics, which are based on what is believed to be good engineering and experience, are listed:

(1) The registration of received color images should be a ground station operation;

* Color Television Incorporated

(2) The signals transmitted from space should be such that after conversion to the NTSC standard, a minimum of spurious color is introduced by beats between the NTSC conversion and the signals received from space;

(3) The received signal should not be adversely influenced by the frequency shift produced by the Doppler effect.

(4) The circuitry at the camera should be straightforward and at a minimum;

(5) The frame rate should be sufficiently high to give continuity of motion to the subject matter of the televised scene; and

(6) The sensitivity of the camera should be as high as possible.

b. SYSTEM A

System A has the same frequency spectrum as the NTSC system, except that it is scaled down to fit the available 1.25-Mc channel (see Figure 3). The bandwidth is reduced to 28 percent of the NTSC signal; the corresponding frame rate should be 28 percent of 30 frames or 8.35 frames per second.

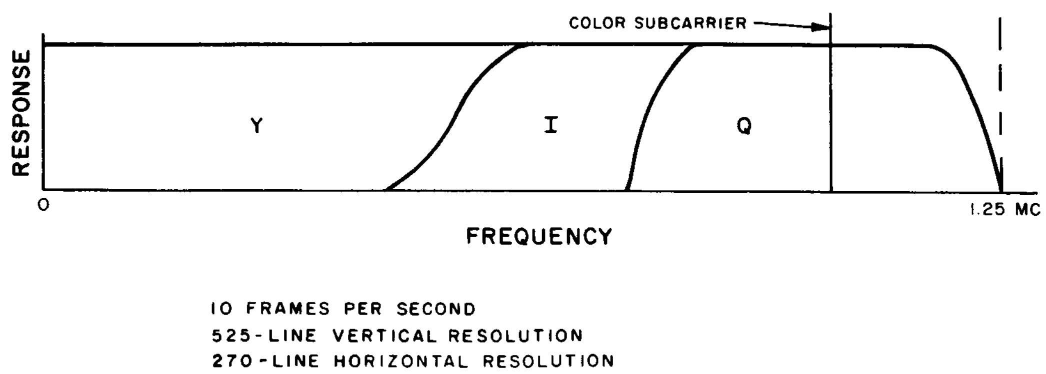


Figure 3. Frequency Spectrum, System A

However, for conversion on the ground, the number of frames per second must have an integral relationship to 30 frames per second; therefore, a frame rate of 10 frames per second is used. At a frame rate of 10 per second, the horizontal resolution will be 270 lines. (Commercial color receivers have resolution in the luminance channel of about 260 lines.) The luminance channel is transmitted at full baseband, and mixtures of red, green, and blue are transmitted in different proportions as the I and Q signals. These two signals are transmitted in quadrature on the common subcarrier. The purpose of this scheme is to reduce the crosstalk introduced by the fact that the I-signal channel utilizes vestigial sideband transmission in order to obtain the required color detail.

Since it is desired that registration of the three images is to be a ground station operation, the transmitted signals cannot be representative of mixture colors as in the NTSC standards. At the camera, the color subcarrier frequency must control the line scan rate in order to produce interlace. In addition, a color phase control burst must be generated and added to the transmitted signal. The additional complexity of the camera circuits is not desirable.

Another difficulty is introduced by phase changes due to the Doppler effect in the propagation path. The present NTSC standard calls for a frequency stability of ± 11 cycles, which on the better color television sets produces a phase change of about 20 degrees. A 4-degree shift produces a visible color change. Calculation indicates that with an earth-orbiting camera a shift of ± 100 cycles would be expected for a NTSC signal at the full NTSC bandwidth. The fact that the NTSC system is scaled down to 1.25 Mc reduces the frequency shift in cycles but does not change the sensitivity to color shift.

Special ground station circuitry, similar to that used in the playback of color tape recordings, is available to correct for the Doppler frequency shift. For example, a "start-stop" oscillator, which generates a constant frequency determined by the frequency of the individually received color bursts, may be used to demodulate the color information. The change in frequency of the incoming signal will produce a phase shift of as much as 2.5 degrees per horizontal picture line. This means that the color at the end of a horizontal line will have shifted from the value at the start of the line by 2.5 degrees. Circuits such as this cannot average the frequency over several color bursts and have very poor noise immunity.

In summary, System A exhibits the following characteristics:

(1) The three color-separation images cannot be registered on the ground;

(2) The required camera circuitry is excessively complex;

(3) The received picture is subject to color changes due to Doppler effect;

(4) The frame rate is 10 frames per second; and

(5) The horizontal resolution is 270 lines.

c. SYSTEM B

The System B frequency spectrum (Figure 4) is the same as that of System A, but in System B, a green, red, and blue signal are transmitted instead of a luminance signal (Y) and difference signals (I and Q). The luminance information is contained in the three color signals. The green picture is transmitted at full baseband. The use of this system was based on signal-to-noise considerations. Since a luminance signal contains only 0.59 green, the green signal made from the luminance will have a signal-to-noise ratio only 0.59 as good as the green signal from a green-only camera tube. This situation exists even if there is no noise in the red and blue signals that are subtracted from the luminance signal to make the green signal. Moreover, a luminance signal made from three received signals at the ground station will have less noise because the noise components add at random and the desired signals add directly. The high-frequency noise is the same regardless of whether the signal carrying the high-frequency detail is luminance or green, since no high-frequency detail is transmitted in either the red or blue channel. Furthermore, the high-frequency noise, which is the only noise that is beat down to low-frequency noise in the color demodulator in the receiver, appears as chrominance noise only.

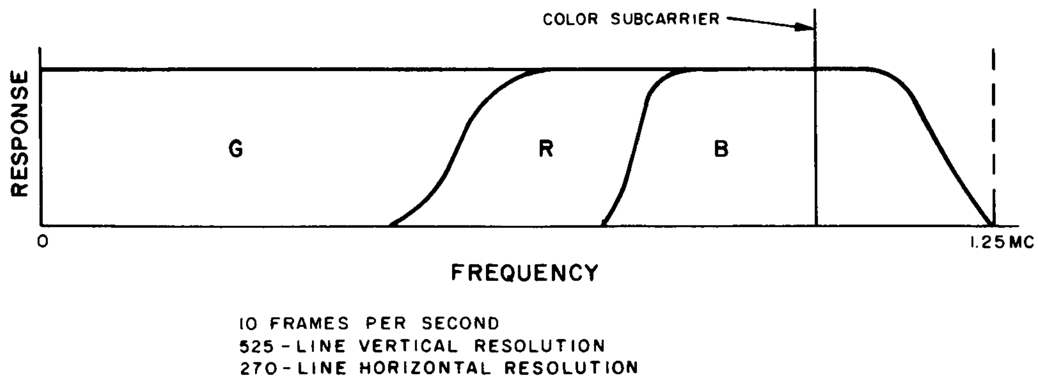


Figure 4. Frequency Spectrum, System B

The red and blue picture signals modulate the interlaced subcarrier in quadrature, and the polarity of either the red or blue signal is reversed on alternate lines. This reversal tends to cancel the quadrature distortion on alternate lines. However, with large phase errors, interline flicker is introduced. A further disadvantage of this system is that Doppler shift in the propagation path produces a serious color stability problem.

In summary, System B exhibits the following characteristics:

(1) The three color-separation images can be registered on the ground;

(2) The required camera circuitry is even more complex than that for System A;

(3) The frame rate is 10 frames per second; and

(4) The horizontal resolution is 270 lines.

d. SYSTEM C

The System C frequency spectrum is shown in Figure 5. In this system, the green picture is transmitted as the wideband signal; the red signal is transmitted as amplitude modulation on a subcarrier that is dot interlaced with the green signal; and the blue signal is transmitted as amplitude modulation on a subcarrier of normal stability located outside of the spectrum occupied by the detail signal and the red sideband. The use of amplitude modulation on the two subcarriers removes the problem of color change due to Doppler effect. The red-signal subcarrier controls the line scan rate so as to produce interlace. The choice between positive and negative amplitude modulation of the color subcarrier is determined by the visibility of the subcarrier. With negative modulation, the amplitude of the subcarrier will be greatest in the dark parts of the picture. With positive amplitude modulation, the amplitude of the subcarrier will be at a maximum in the brighter parts of the picture, where it will have a minimum of visibility.

Interlaced scanning is a method of reducing flicker at low frame rates, where frame storage is inadequate. Normally, this storage is due only to phosphor decay and eye persistence. In a system where there is full frame storage in the scan conversion equipment, interlacing of the scanning raster has no bearing on the flicker of the final image. All that any type of interlacing will do in this case is to change the fine structure on the edges of objects that are blurred due to motion. The only exchange possible is to expose the camera for only part of a frame time (at the expense of camera sensitivity) to produce a series of sharp pictures without blurred edges due to motion.

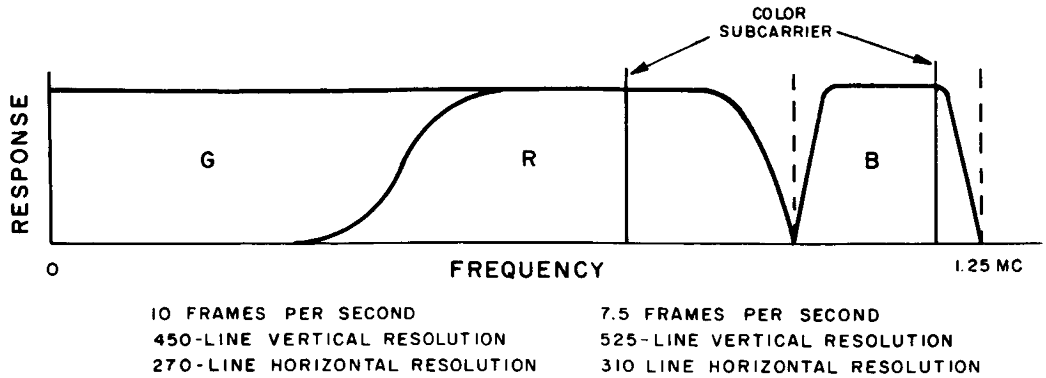


Figure 5. Frequency Spectrum, System C

With storage and conversion on the ground, no purpose is served by the use of interlaced scanning. Also, by not using interlaced scanning, the highest correlation between adjacent lines can be obtained, and the most effective use of a comb filter can be made to separate the red and green signals with a minimum of spurious signals.

The available bandwidth of 1.00 Mc is 22 percent of that of the corresponding 4.5-Mc NTSC signal. To maintain a resolution of 325 lines, the frame frequency must be reduced to 22 percent of 30 frames per second, or 6.6 frames per second. However, in order to allow conversion to NTSC standards on the ground, a frame frequency of 7.5 frames per second must be used. At this frame rate, the theoretical horizontal resolution is 285 lines, which is ample to supply all the horizontal picture detail that can be used by present-day monochrome and color receivers. Due to the beat of the color subcarrier with picture detail, the resolution is actually limited to about 260 horizontal lines on both color and monochrome receivers.

The subjective detail in a television picture is the product of the horizontal and vertical detail, taking into account the loss of detail in the vertical direction due to the random position of the scanning lines with respect to detail in the picture. The maximum detail at a given frame results when the horizontal detail and the effective vertical detail are equal. The product of the two has a broad maximum.* Laboratory tests have shown that for a 4.5-Mc channel, 441 lines is the optimum value at 30 frames per second. However, in selecting the number of lines for our present commercial system, an additional factor was taken into consideration; i.e., the visibility of the line structure. With the broad maximum of picture detail, the industry agreed that 525 lines was the preferred choice. In a system where scan-conversion equipment controls the line structure of the final picture, the number of lines should be selected to produce the maximum subjective

*Kell, Bedford, Fredendall; "A Determination of Optimum Number of Lines in a TV System." RCA Review, Vol. 5, 1940.

detail in a picture, within the constraints of bandwidth and frame rate. If it is desired to increase the frame rate from 7.5 to 10 frames per second, the number of scanning lines must be reduced. With 260-line horizontal resolution, equal horizontal and vertical detail will be obtained with about 400 scanning lines. This reduction in number of lines allows the frame rate to be increased in the ratio 525/400 or 1.3 × 7.5 or 10 frames per second. The reduction of vertical detail in going from 525 to 400 lines can be largely overcome by the use of equalization in the vertical direction.

In summary, System C exhibits the following characteristics:

(1) The three color-separation images can be registered on the ground;

(2) Camera circuit complexity is at a minimum;

(3) The frame rate is 7.5 frames per second with full vertical detail. A rate of 10 frames per second may be used if vertical equalization is used to correct for the loss in vertical detail; and

(4) The system is not subject to color changes due to Doppler effect.

e. SYSTEM D

The System D frequency spectrum is shown in Figure 6. In this system, the green picture is transmitted as the wideband signal, and the red and blue signals are each used to modulate separate subcarriers of normal frequency stability. The use of amplitude modulation removes the problem of color change due to Doppler effect. The circuits required at the camera are relatively simple.

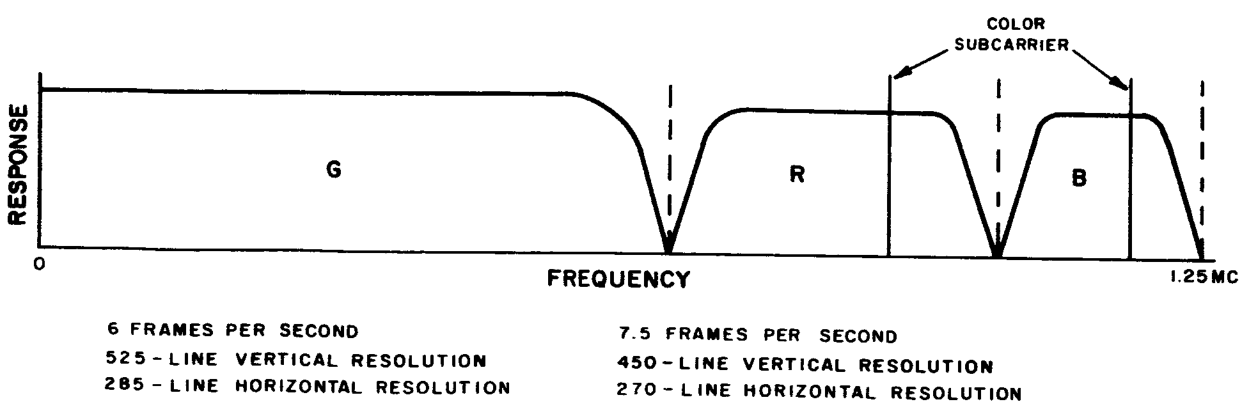


Figure 6. Frequency Spectrum, System D

The frame rate must be reduced in the ratio of 1.25/7.1 which equals 17.6 percent of 30 frames per second, or 5.3 frames per second, to maintain a resolution of 325 lines. For scan conversion, this frame rate is changed to 6 frames per second, resulting in a horizontal resolution of 285 lines.

In summary, System D exhibits the following characteristics:

(1) The three color-separation images can be registered on the ground;

(2) Camera circuit complexity is at a minimum;

(3) The frame rate is 6 frames per second;

(4) The horizontal and vertical resolutions are 285 and 525 lines, respectively; and

(5) The system is not subject to color changes due to Doppler effect.

f. SYSTEM E

The System E frequency spectrum is shown in Figure 7. In this system, the green picture is transmitted as the wideband signal, and the red and blue pictures are transmitted sequentially on alternate scanning lines by means of a single frequency-modulated subcarrier. The red and blue picture information is stored for a line period so that red and blue picture information is available at the same time. Since half the red and blue lines of the picture are not transmitted, detail in the vertical direction would on the average be reduced. An all-green picture, however, will suffer no reduction of detail. For all red or blue pictures, the vertical resolution would be reduced to one-half resolution, or 262 lines. For a white picture, 40 percent of the vertical detail signal would be reduced to 262 lines. The green channel must be restricted in bandwidth so as not to pass the color subcarrier; even so, the frequency modulation sidebands would produce spurious color signals.

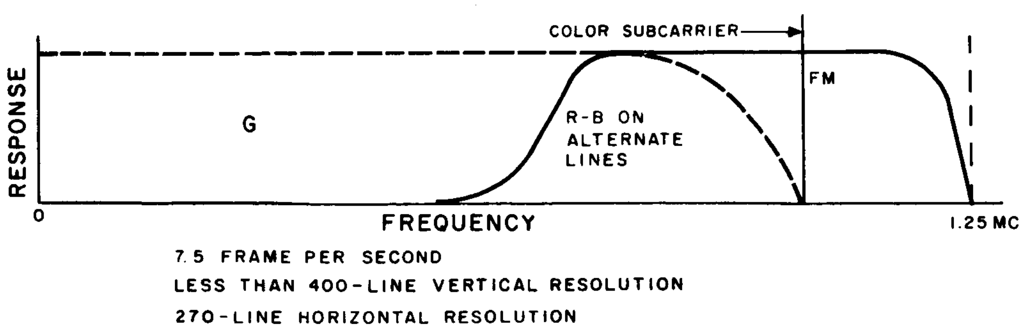


Figure 7. Frequency Spectrum, System E

A comb filter cannot be used to remove the color carrier and its sidebands because the required fixed relation does not exist between the line scan rate and the color subcarrier. The percentage of the total available spectrum that may be used for the green picture is the same as that for System C. A horizontal resolution of 285 lines may be obtained at 7.5 frames per second. The use of a vertical aperture equalizer to increase the vertical detail would not be satisfactory due to the omission of alternate lines of red and blue.

In summary, System E exhibits the following characteristics:

(1) The three color-separation images can be registered on the ground;

(2) The camera circuits are complex because of the requirement to transmit the red and blue pictures on alternate lines;

(3) The frame rate is 7.5 frames per second with reduced vertical resolution; and

(4) The system is not subject to color changes due to Doppler effect.

g. SYSTEM F

The System F frequency spectrum is shown in Figure 8. The spectrum is the same as that of System A, which is a scaled-down version of the NTSC spectrum. In System F, the green picture is transmitted as the wideband signal, utilizing the full width of the frequency channel. The red and blue picture signals are transmitted sequentially on alternate scanning lines by means of a single amplitude-modulated subcarrier. The subcarrier controls the line scan to produce dot interlacing. A comb filter separates the color subcarrier and its sidebands from the green picture signal.

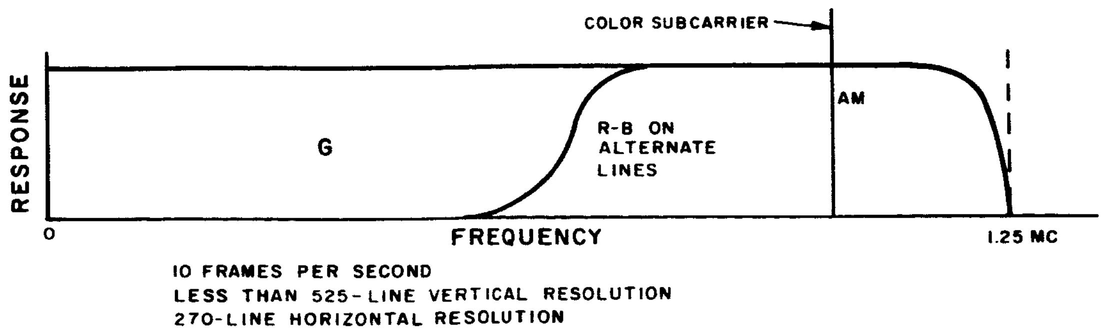


Figure 8. Frequency Spectrum, System F

The red and blue color pictures are stored for a line period so that all three pictures are available at the same time. Since the red and blue lines of the picture are used twice, the detail in the vertical direction is a variable between the full 525 lines and some lesser value, as in System E. For example, a green object would have the full 525 lines vertical resolution, but a red object would contain only half the 525 lines in one frame since the same red picture information is used on two lines.

In summary, System F exhibits the following characteristics:

(1) The three color-separation images can be registered on the ground;

(2) The camera circuits are complex because of the requirement to transmit the red and blue pictures on alternate lines;

(3) The frame rate is 10 frames per second;

(4) The horizontal resolution is 270 lines;

(5) The vertical resolution is variable between 525 lines and some lesser value, depending on picture color content; and;

(6) The system is not subject to color changes due to Doppler effect.

h. SUMMARY

The properties of the various systems considered are compared in Table 1. Of the six systems, only Systems C, D, and F possess properties that make them worthy of further consideration for application to the space program.

A comparison of Systems C and D shows that they differ mainly in the way that the frequency spectrum is utilized. In System D, the red and blue signals are each carried as modulation on separate subcarriers. In System C, the red subcarrier is in the same frequency band as the green signal and is dot interlaced with the line scan. This method of interlacing permits the red and green signals to be separated by means of a comb filter at the ground station. The interlacing of the subcarrier permits an increase in frame rate from 6 to 7.5 frames per second at 400 scan lines. The improved continuity of motion due to the increase in frame rate justifies the additional circuit complexity required for the interlace.

TABLE 1. COMPARISON OF SYSTEM PROPERTIES

System	Conforms to Bandwidth Requirement	Horizontal Resolution	Vertical Resolution	Frame Rate (frames per second)	Ground Conversion	Registration at Receiver	Spurious Signals	Sensitive to Doppler	Good Camera Sensitivity	Complexity of Camera Circuitry
A	Yes	270	525	10	Yes	No	No	Yes	Yes	Excessive
B	Yes	270	525	10	Yes	Yes	No	Yes	Yes	Excessive
C	Yes	310 270	525 450	7.5 10	Yes	Yes	No	No	Yes	Minimum
D	Yes	285	525	6	Yes	Yes	No	No	Yes	Minimum
E	Yes	270	Less than 400	10	Yes	Yes	Yes	No	Yes	High
F	Yes	270	525 to 262	10	Yes	Yes	No	No	Yes	High

A comparison of System C and System F is presented in Table 2. Of the six NTSC type systems considered, Systems C and F are preferred; there being minor advantages of one over the other.

TABLE 2. COMPARISON OF SYSTEMS C AND F

System C	System F
Camera Circuit Complexity	
1. Line scan controlled by color subcarrier	1. Line scan controlled by color subcarrier. 2. Switching circuits between Red and Blue pictures at line rate. 3. Generation of color switching signals to be transmitted with picture signal.
Vertical Picture Detail at 10 Frames Per Second	
1. Reduced from 525 to 450	1. Full 525 line Green picture detail. 2. 212 line detail in Red and Blue pictures. 3. In White, 40 percent of the detail signal is reduced to 212 lines.
Vertical Aperture Equalizer and Comb Filter Efficiency	
1. Maximum redundancy between adjacent lines giving maximum efficiency.	1. Reduced redundancy due to alternate line scanning causes reduced efficiency.
Communication Considerations	
1. Transmitter deviation reduced to accommodate second sub-carrier.	1. The problem of beats between the two subcarriers is lessened.

5. Field Sequential System

The field sequential system originally proposed for broadcast service has been discussed earlier in this report. In spite of its unacceptability for broadcast service, the existence of a different set of constraints for space color television made a review of this system imperative.

The realistic constraint on bandwidth (1.25 Mc) leads necessarily to the use of frame rates much slower than those used for standard broadcast. How much slower depends, of course, upon the amount of detail it is desired to depict, and upon the degree of realism desired in depicting motion; these two factors may be traded, one against the other. Very slow frame rates (for example, one frame per second or less) would be adequate for transmitting a succession of still pictures, or of snapshots of scenes containing motion. For adequate depiction of the illusion of motion, 6 frames per second is considered to be a minimum.

One of the advantages of the field sequential system in the form proposed for broadcast operation lay in the fact that a single camera tube was used, being exposed and scanned in sequence to the red, green and blue image components. The color fringing which was a disadvantage of the system arose from the fact that it took 1/16 second to complete the cycle of scanning three color fields (1 each of red, green and blue). For space TV (1.25 Mc) about 0.3 second is required, so the color fringing should be more objectionable. A field sequential system can be designed to have three camera tubes, with registered images and scanning; with this arrangement the three tubes can be exposed simultaneously through their respective separation filters, and scanned in sequence. This arrangement would prevent color fringing, but would reduce the effective sensitivity of the camera by the factor of shutter duty cycle (that is, shutter opening time divided by frame time). An additional factor, whose effect could be significant, would be introduced by the decay or degradation of the exposed images during the interval while they were awaiting scanning. Thus, the field sequential system suffers from a substantial disadvantage where the imaging of moving objects is desired.

The trading of picture resolution against frame rate, in the original field sequential system, was subject to the limitation that equal time and bandwidth were devoted to the three color fields. This limitation is a necessary consequence of a configuration that combines a single camera tube with a rotating filter wheel. One of the important features embodied in the NTSC standards was the recognition that equal resolution was not required in the three separation images; that in fact much less was needed in blue and red, than was required for green. Thus a more efficient use was made of the available video bandwidth than could be achieved with the original field sequential system; for a system where bandwidth was in short supply, this concept was very important.

An even more drastic limitation on available bandwidth is inherent in the space television system for use in motion depiction. Thus it is even more essential to make efficient use of the available bandwidth in this application.

Bandwidth can be utilized efficiently in the field sequential system by devoting different times to the transmission of each of the three color fields comprising the complete color picture. This method can be implemented by providing three separate camera tubes, each with its own color filter (red, green or blue), deflection yoke, and circuits. The tubes would be exposed simultaneously by means of a shutter. Then, by means of suitable logic circuits associated with the deflection circuits, the three camera tubes would be read out in sequence. The total frame time can be apportioned in any desired manner among the three images. The problem of color fringing can thus be overcome, at the expense of sensitivity, by installing a shutter. Design of a suitable shutter for continuous operation at the desired frame rate (six per second or greater) is not a minor problem.

Single camera tube operation is also possible with non-equal time sharing between the color separation fields. It is accomplished by (1) arranging an optical system and beam splitter so that the three separation images are formed one above the other on the camera tube target, and (2) varying the scanning parameters as the three areas are scanned. As an aid to simplifying the logic required of the deflection circuits, the red and blue images may be anamorphized, that is, distorted so that the horizontal and vertical magnifications are not equal. For example, the magnification of the red and blue images in the vertical direction may be only 1/3 that of the horizontal, whereas the magnification of the green image is uniform in both the horizontal and vertical directions. Then a single vertical scanning sawtooth waveform would automatically devote 1/5 of the frame time each to red and blue, and 3/5 to green. A single horizontal deflection frequency would divide the total number of scan lines in the same ratio. Provision of the necessary optics would be difficult, although anamorphic lenses are in current use in cinematography. Eventually, fiber optics will probably be able to provide an anamorphic image transform. It is considered that the single tube camera of the foregoing general type represents a possibility for future development. Its only advantage over the three tube camera would be its smaller volume and weight.

6. Line Sequential System

a. GENERAL

Line sequential scanning divides each scanning line into segments, devoting each segment to the generation of a video signal corresponding to one of the color separations. It was originally proposed as one of the early contenders for use as the standard system of color television broadcasting. However, this proposal was made without considering the use of restricted resolution in blue and red (as practiced successfully in the present NTSC standards used in color TV broadcasting). As a consequence, the overall effective resolution was degraded because the green channel, which conveys the most detail, shared equally with red and blue in the available transmittable picture elements. This system also produced undesirable stroboscopic effects, referred to as " line crawl" , arising from the use of interlaced scanning. These two defects were sufficient to cause rejection of the system as the broadcasting standard, in spite of the advantage gained by eliminating the synchronous color filter wheel that was required by the field sequential system.

Conditions in the present case are different from those prevailing at the time the broadcast standards were under consideration. The bandwidth of 1.25 Mc will not support a television frame rate that would be sufficient to prevent flicker in a visual display; therefore, it is necessary to depend on scan conversion, which renders motion frame rate independent of picture frame rate, to provide a flickerless display. Scan conversion will be used in any event to convert the space system pictures to broadcast standards; frame rate will therefore be limited only by the combination of resolution and available bandwidth. Thus, there is no point in using interlaced scanning for the camera; and hence, the problem of " line crawl" will not exist. By either optical or electronic means, the relative time sharing among red, green, and blue scanning can be established at any desired set of values; and thus, the principle of higher resolution in green than in red or blue can be implemented.

A line sequential system that embodies several novel techniques has been developed by RCA during the course of this study. A description of the proposed system follows.

b. VARIABLE-LINE SEQUENTIAL SYSTEM

The camera head contains three camera tubes associated with a dichroic beam splitter, and appropriate optical trim filters to provide the proper spectral characteristics for picture taking. The camera lens provided the three color separation images, one to each of the three camera tubes, through the beam splitter and trim filters. This method is the standard practice in modern television broadcast cameras.

The scanning system represents the basic point of departure from current television broadcast practice. Instead of scanning the red, green, and blue tubes simultaneously, the deflection is programmed by logic circuits which cause the green tube, the red tube, and the blue tube to be scanned in a specific sequence during successive scan lines. The scanning sequence, and the resulting video signal, are both illustrated in Figure 9. It is seen that there are 500 active scanning lines assigned to green, and 250 each to blue and red. In the first scanning line, 167 microseconds are allocated to scanning the green image; the ensuing 56-microsecond interval is used to scan the blue image. The second scan line commences (after a suitable interval of 33 microseconds for horizontal blanking and synchronizing signal), and the next 167-microsecond period is used to scan the second line of the green image. The logic circuits then activate the scanning of the red image, whose first line is now scanned, for a period of 56-microseconds. After a period of 33 microseconds for blanking and synchronizing signals, the cycle just described is repeated. The sequence of scanning lines is then green, blue, green, red, green, blue, green, red, and so on consecutively until 500 green lines, 250 blue lines, and 250 red lines have been scanned. The frame rate (i.e., vertical scan frequency) is 7.5 frames per second; the line scan rate is 3840 cps for the green tube and 1920 cps for the red and blue tubes. A short intercolor blanking interval of 4 microseconds is used to separate the blue or red signal from the green.

Typical scanning waveforms to accomplish the desired program are shown in Figure 10. It is seen that the same scanning waveform is used on both the red and blue tubes, the appropriate tube being gated "on" in alternate lines.

The system described will require a means of identifying the video signals for the alternate red and blue lines to permit their proper display at the receiver. There is a variety of suitable methods which can be used; the alternate horizontal sync pulses can be widened, or a sync burst can be placed on the back porch of the horizontal sync pulse.

c. HYBRID FRAME-LINE SEQUENTIAL SYSTEM

A hybrid form which combines the features of both the field and line sequential systems was investigated briefly; the basic concept is shown in Figure 11. In this system, the three separation images are placed upon a single camera tube target by means of a suitable beam splitter. The blue and red separation images each have a magnification of one-half, relative to the

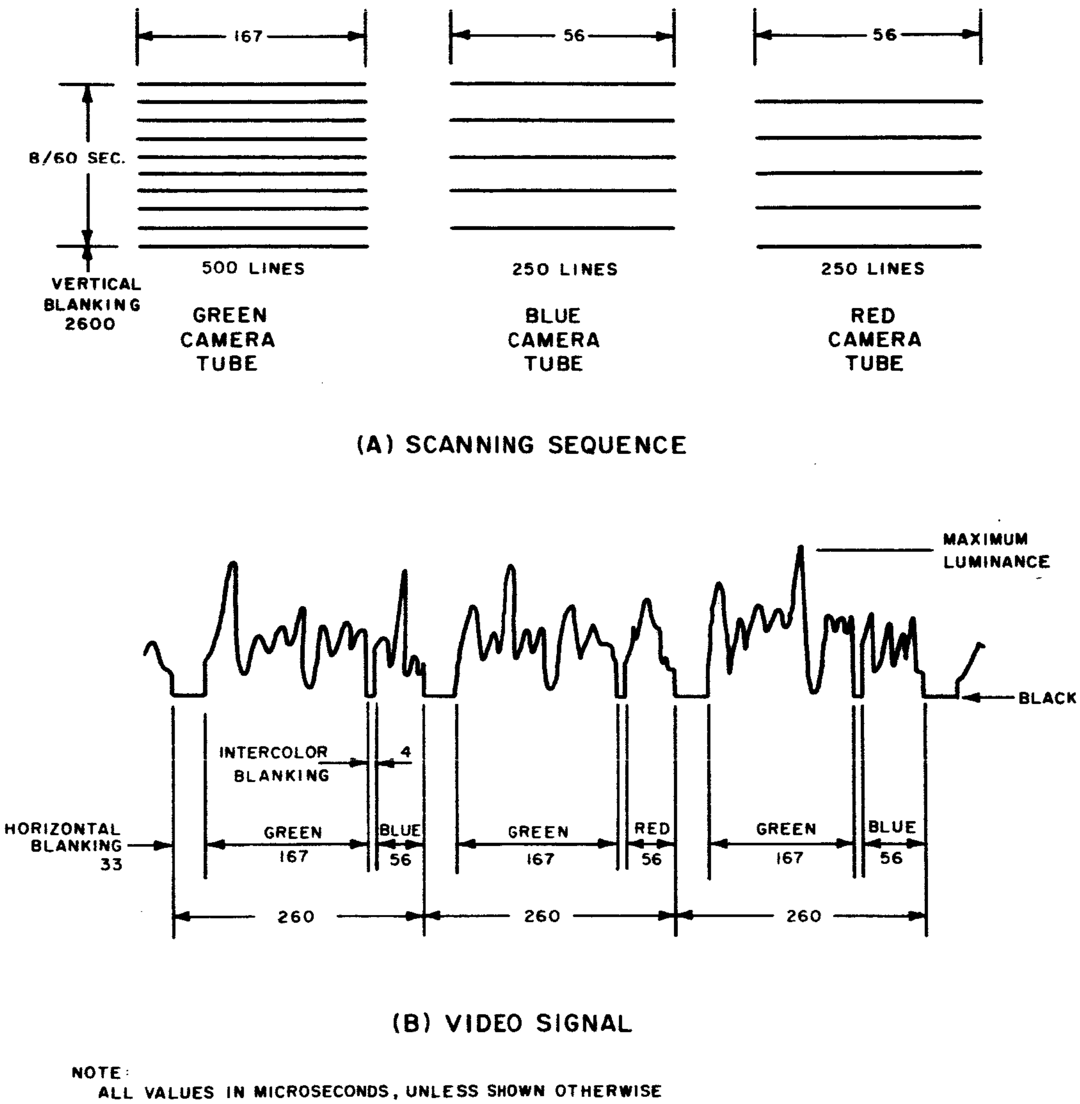


Figure 9. Scanning Sequence and Video Signal, Proposed Line Sequential System

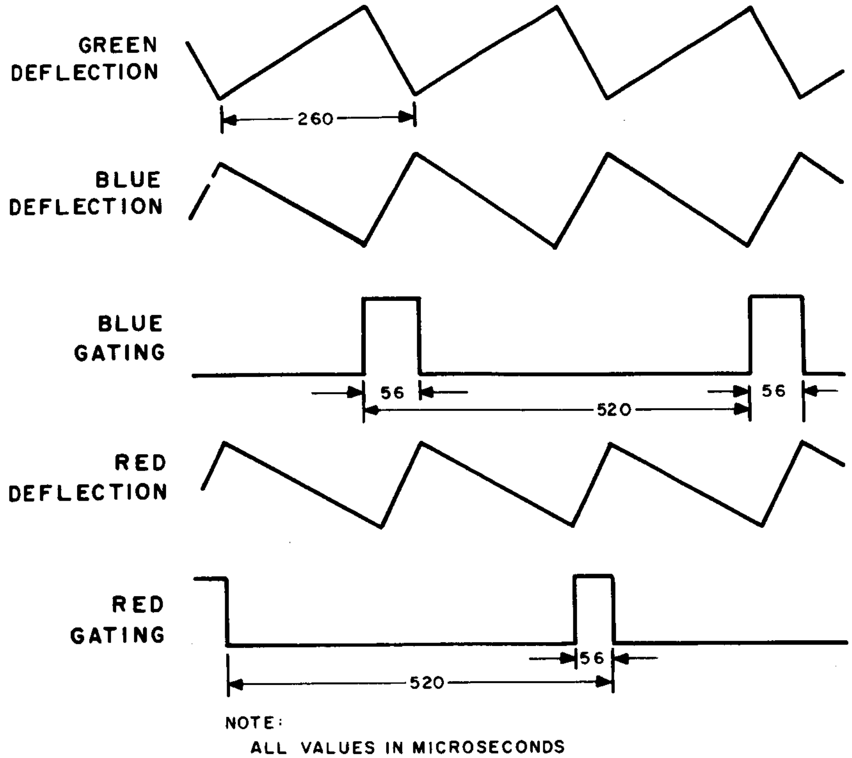
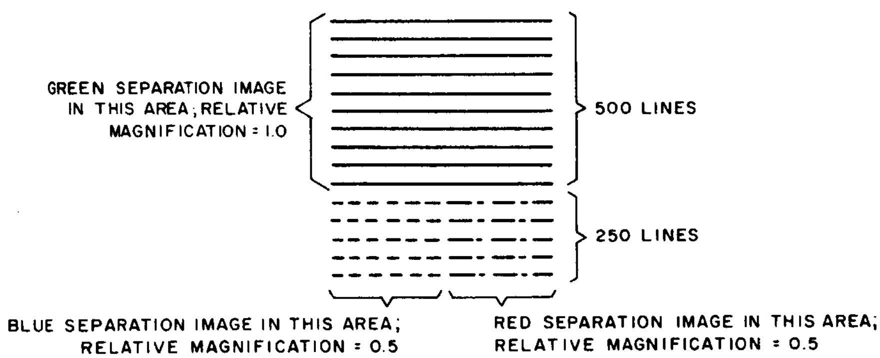


Figure 10. Typical Scanning and Gating Waveforms, Proposed Line Sequential System



A. ARRANGEMENT OF SCAN RASTER AND COLOR SEPARATION IMAGES ON CAMERA TUBE TARGET

BAND WIDTH (VIDEO)	1.25 MC
FRAME RATE	7.5 FRAME PER SEC
HORIZONTAL FREQUENCY	5930 CPS
t_H	169 μSEC
t_H (ACTIVE) (15 PERCENT BLANKING)	143 μSEC
HORIZONTAL RESOLUTION (GREEN)	270 TV LINES
HORIZONTAL RESOLUTION (RED AND BLUE)	135 TV LINES
VERTICAL RESOLUTION (GREEN)	350 TV LINES
VERTICAL RESOLUTION (RED AND BLUE)	175 TV LINES

B. TABULATION OF SIGNIFICANT PARAMETERS

Figure 11. Hybrid Frame-Line Sequential System

green image. The three images are oriented so that vertical image lines in each of the images are normal to the scan lines. The whole target is then scanned with 750 lines, the first 500 of which cover the green image. The first of the next 250 lines covers a line of the blue separation image and then, continuing across the target, scans a line of the red image. The next of this group of 250 lines repeats this scanning sequence, scanning first a blue image line and then a red image line. The process is continued until each of the 250 lines has scanned the blue and red images. There then follows a vertical blanking interval of 5 percent (6667 microseconds) during which a vertical synchronizing signal is transmitted.

This system is attractive because it could lead to a very compact camera requiring only a single camera tube. However, the optical problems are formidable; the system requires beam splitting, two values of magnification, and the correct relative placement of the separation images upon the camera tube target. These problems could perhaps be solved by the use of fiber optics together with a fiber optic faceplate, but the transformation required appears to be difficult to achieve. The sensitivity of the camera will also suffer because of the area sharing and the inefficiency of the optics.

The scanning program used could be arranged to operate with a three camera tube-system, but it would then be no more compact than any other arrangement which used three tubes.

The hybrid system described has some advantages over a pure frame-sequential system, particularly in respect to color fringing. It has no fringing between blue and red; however, the delay of green scanning would produce fringing in green when open shutter operation is used. It was concluded that the hybrid system had most of the disadvantages of the field sequential system.

d. STRIPE-FILTER LINE SEQUENTIAL CAMERA SYSTEM

The line sequential system proposed provides the interesting possibility of a two-tube camera of novel design. In such a camera the green camera tube is used normally, with a suitable trim filter, to furnish the green separation video signal. The red and blue components are reflected to a striped separation filter, which consists of an array of alternating red, blue, and opaque strips placed in the focal plane of the picture-taking lens. The arrangement is shown in Figure 12. The stripes are imaged upon the red-blue tube by a relay lens; the stripes are oriented to be normal to the scanning lines. The pitch of the stripes is related suitably to the resolution desired; black stripes are provided after each pair of color filters to enable suitable gating, and processing circuits at the camera separate the red and blue information. A block diagram of

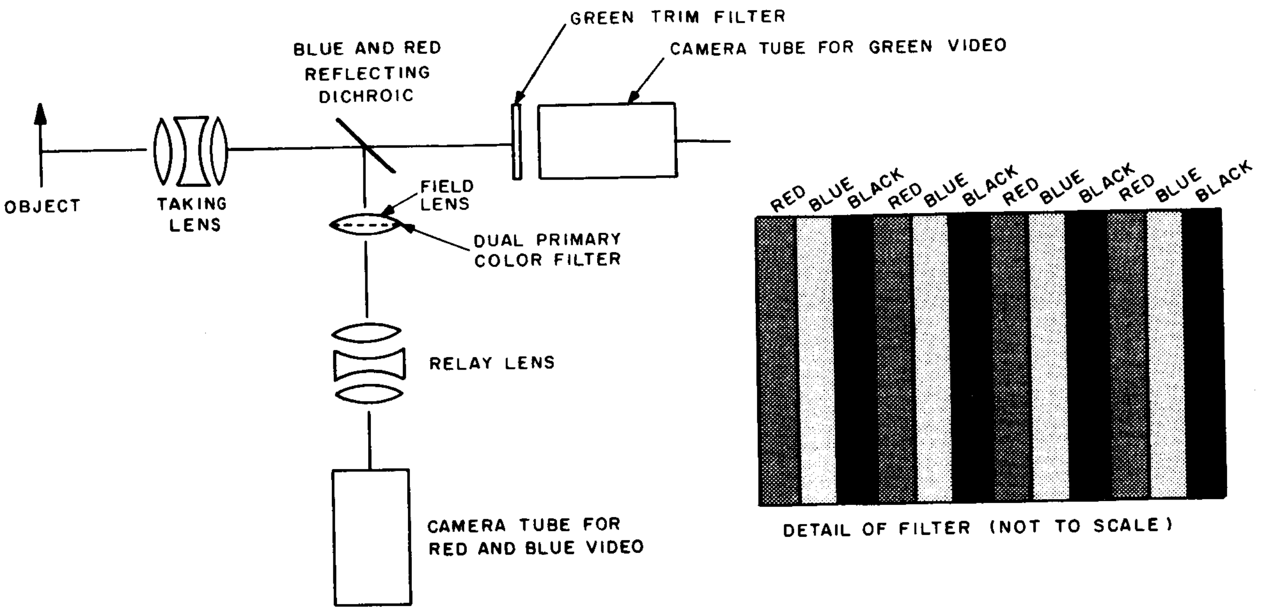


Figure 12. Optical System for Color Stripe Camera

a typical processing circuit is shown in Figure 13. As shown in the diagram, a gate pulse is obtained by sensing the black stripes or the striped filter, and these pulses are used to separate the blue and red separation signals. These signals are then filtered in a pair of low-pass filters to remove the gating pulses. A second gate, actuated at half the line frequency, is used to alternate the red and blue separation signals.

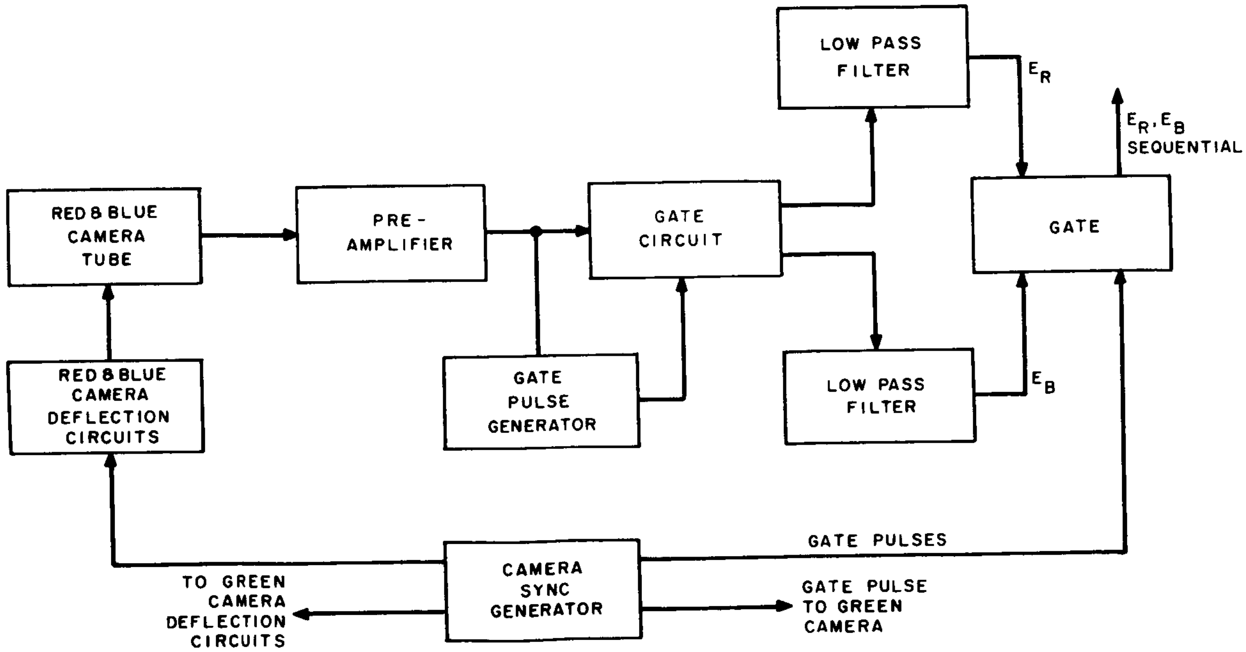


Figure 13. Typical Processing Circuit for Color Stripe

e. SIGNAL-TO-NOISE RATIO

For the space application, the variable-line sequential system has a signal-to-noise advantage over a system, that uses a NTSC-type signal. The signal current from an image tube such as a vidicon or SEC vidicon is proportional to the rate at which the signal is read out, i.e.

$$I = \frac{Q}{\Delta T}.$$

Therefore, for a given exposure time (in the case of open shutter operation, frame rate), the signal increases as the active frame period decreases. The noise in the video system is essentially proportional to the square root of the bandwidth.

A comparison was made between System C of the NTSC related space television systems, and the variable-line sequential system. For System C, the green bandwidth is 1.0 Mc, the red 0.350 Mc, and the blue 0.120 Mc. For the line sequential system, the video bandwidth for all three colors is 1.25 Mc.

System C has 14 percent horizontal blanking and 500 active lines out of a total of 525 lines scanned. The actual time for scanning during each frame is:

$$\left(\frac{1}{7.5 \text{ frames per second}}\right) \left(\frac{500 \text{ active lines}}{525 \text{ scan lines}}\right) (0.86) = 0.109 \text{ second.}$$

For the variable-line sequential system, the active scanning time varies, depending upon the primary color being scanned.

For green it is:

$$500 \text{ actives lines} \times 167\mu \text{sec/line} = 0.0835 \text{ second}$$

For red and blue it is:

$$250 \text{ actives lines} \times 56\mu \text{sec/line} = 0.014 \text{ second}$$

To compare the signal-to-noise ratios of the variable-line sequential system and System C, we have

$$\frac{S/N_{LS}}{S/N_C} = \left(\frac{T_C \sqrt{B_c}}{T_{LS}\ B_{LS}}\right)$$

where

S/N_{LS} is the signal-to-noise ratio of the variable-line sequential system;

S/N_C is the signal-to-noise ratio of System C;

T_C is the active scan time per frame of System C;

T_{LS} is the active scan time per frame of the variable-line sequential system;

B_C is the bandwidth of the System C color channel; and

B_{LS} is the bandwidth of the variable-line sequential system.

For the green channel

$$\frac{S/N_{LS}}{S/N_C} = \frac{0.109}{0.0835} \times \sqrt{\frac{1}{1.25}} = 1.17$$

For the red channel

$$\frac{S/N_{LS}}{S/N_C} = \frac{0.109}{0.014} \times \sqrt{\frac{0.35}{1.25}} = 4.12$$

For the blue channel

$$\frac{S/N_{LS}}{S/N_C} = \frac{0.109}{0.014} \times \sqrt{\frac{0.12}{1.25}} = 2.41$$

These figures would depend somewhat upon the nature of the noise, but a substantial advantage is indicated for the variable-line sequential system, particularly in the red and blue channels.

7. The Luminance Signal

The NTSC color television system generates a set of three tristimulus values for each point of the image scanned by the camera tube. These values are designated as R, G, and B, and each is defined by the amount of additive color primary it contains. The primaries are identified by the following set of coordinates on the CIE* chromaticity diagram:

---

*Commission Internationale de L' Eclairage; also called the International Commission on Illumination (ICI).

Primary	CIE Coordinates	
	x	y
Red	0.67	0.33
Green	0.21	0.71
Blue	0.14	0.08

The tristimulus values represent the amounts of these respective primaries which are required to enter into an additive match of the color being transmitted. Since the CIE coordinates shown are representative of the actual physical phosphors used in the color display tube, usually the corresponding electrical signals representing R, G, and B can be used directly to control the intensity of the red, green, and blue phosphors of the display. The relative values of R, G, and B are chosen so that they are equal at illuminant C (CIE chromaticity coordinates: $x = 0.310$, $y = 0.316$).

The tristimulus values, R, G, and B, generated at the camera, are converted to electrical signals by using the relationships:

$$E'_R = KR^{\frac{1}{\gamma}}$$

$$E'_G = KG^{\frac{1}{\gamma}}$$

$$E'_B = KB^{\frac{1}{\gamma}}$$

where

γ is the "gamma" of the receiver displays (assumed to have a value of 2.2), and

K is a constant of proportionality.

The luminance (Y) of the transmitted signal is given by the colorimetric equation,

$$Y = 0.30\ R + 0.59\ G + 0.11\ B,$$

but it is not transmitted in this form. Instead, it is transmitted indirectly by means of a monochrome signal (E'_Y) which is indirectly representative of luminance, and is given by

$$E'_Y = 0.30\ E'_R + 0.59\ E'_G + 0.11\ E'_B$$

Recently cameras have been developed which transmit a monochrome signal (E''_Y) that is more directly related to luminance, and is given by

$$E''_Y = KY^{\frac{1}{\gamma}}$$

Examination discloses that E''_Y is not identical with E'_Y except for colors near white. This fact has been encountered in a recent class of cameras wherein a luminance signal is produced by a single camera tube equipped with a filter having a shape identical to the luminosity function. It was originally intended to use two auxiliary tubes, one to produce the red separation signal and the other to produce the blue signal. Since these two tubes did not need to produce as much resolution as that required of the luminance tube, they were made of smaller size. Thus, the luminance camera tube was an image orthicon, and the two color tubes were vidicons. It was soon found that this arrangement produced intolerable infidelity in the reproduction of green. A part of this infidelity was due to shading, since the three tubes had different characteristica in this respect. Other significant factors contributing to the difficulty were differences in gamma characteristics, and the effect of the difference between E'_Y and E''_Y. These problems were solved by the addition of a third auxiliary tube, equipped with a green-taking filter; consequently, the final camera had four tubes, consisting of the luminance tube (image orthicon) and three auxiliary tubes (all vidicons - one each for red, green and blue). This arrangement has been very successful in broadcast cameras.

The broadcast system operates by transmitting the following quantities:

(1) The luminance signal, E'_Y, which is given by

$$E'_Y = 0.30\, E'_R + 0.59\, E'_G + 0.11\, E'_B \tag{1}$$

(2) The chrominance signal, which is a subcarrier modulated by two color signals, designated I and Q, in quadrature. The I and Q signals are linear combinations of the color-difference signals ($E'_R - E'_Y$) and ($E'_B - E'_Y$) as given by

$$I = 0.74\,(E'_R - E'_Y) - 0.27\,(E'_B - E'_Y) \tag{2}$$

$$Q = 0.48\,(E'_R - E'_Y) + 0.41\,(E'_B - E'_Y) \tag{3}$$

Since equations 1, 2, and 3 represent members of a family of linear simultaneous equations, direct solutions exist for E'_R, E'_G, and E'_B. These solutions, when applied to a display to control the outputs of the red, green, and blue phosphors, will lead to exact color rendition providing that (1) the phosphors conform to the specified color coordinates of the CIE chromaticity diagram, and (2) the gamma of the display is the inverse of that at the transmitter. When E'_R, E'_G, and E'_B are obtained from a set of three similar camera tubes and $(E'_R - E'_Y)$ and $(E'_B - E'_Y)$ are obtained by suitably matrixing these three signals, exact values of $(E'_R - E'_Y)$, $(E'_G - E'_Y)$, and $(E'_B - E'_Y)$ can be obtained by demodulating the subcarrier at the receiver at suitable demodulation angles. When these three basic quantities are combined with E''_Y (i.e., $KY^{1/\gamma}$), some lack of color fidelity should theoretically be experienced; but it is small, and its effects are distributed over the three primaries. This type of operation is obtained from the 4-tube camera, which experience shows to be highly satisfactory. Conversely, the 3-tube version (with luminance generated by one tube) created intolerable color errors, which occurred mostly in the green channel.

In the case of space color television, similar situations arise. It has been deemed inadvisable to require registration of the camera tubes in the spacecraft. As a result, any thought of transmitting quantities like $(E'_R - E'_Y)$ and $(E'_B - E'_Y)$ must be abandoned, since these quantities can only be obtained as a linear combination of the video outputs of the three camera tubes (including both positive and negative signs), and this method requires onboard registry. It would be possible to generate E''_Y in one camera tube by the use of a luminosity filter, but it has been seen in the preceding discussion that this must be accompanied by the generation of E'_R, E'_G, and E'_B in three other camera tubes. If these quantities could be matrixed to generate $(E'_R - E'_Y)$ and $(E'_B - E'_Y)$, satisfactory colorimetric results could be achieved, but this would also require onboard registry. Thus, if E''_Y is generated in one camera tube, three more camera tubes must be provided and their individual outputs must be transmitted for matrixing at the ground station after ground registry. Thus four signals, E''_Y, E'_R, E'_G, and E'_B would have to be transmitted. Obviously, there is redundancy since only three of these basic quantities are required to specify a color; thus, the waste of transmitter bandwidth would be intolerable.

Because of the desirability of ground registry on the one hand, and in view of the experience with luminance transmission as recounted in the preceding discussion, it appears that the monochrome signal for space color television must be something other than "luminance" (using the term somewhat loosely to mean $E''_Y = KY^{1/\gamma}$; the use of E'_Y being excluded by its requirement of onboard registry). The only exception to this statement would be to choose a gamma (γ) equal to 1 for the spacecraft system, and correct for gamma on the ground. This approach would result in an unfavorable signal-to-noise ratio, which accounts for why it is not being used in broadcast service.

Since the green signal carries most of the luminance information, it appears to be the logical choice for the monochrome signal. In that case, an E'_Y luminance signal can be provided for broadcast transmission by matrixing accomplished at the ground station as an adjunct to the scan-conversion operation.

In view of the foregoing discussion, it is recommended that green E'_G be used as the "luminance" signal, and that the other two colorimetric quantities be transmitted by E'_R and E'_B signals.

8. Bandwidth Compression Study

a. GENERAL

The possibility of band compression was investigated from the viewpoint of efficient use of available bandwidth. A television spectrum consists of a line spectrum, with the lines located at harmonics of the scanning line repetition rate. Motion of the object broadens these lines, but even so definite spaces remain. The NTSC system used in standard color television broadcasting makes use of these gaps to carry the line spectrum of the chrominance subcarrier. Use of corresponding techniques for space television was considered, and has been discussed in another section.

Effective band compression is also obtained by taking advantage of the lesser requirement for resolution in the red and blue separation images. This technique is used very effectively in the NTSC system and was also included in all the systems considered for space color television.

b. FRAME RATE

In broadcast color television, the motion frame rate and the display frame rate are identical. The frame rate is set by the requirement for a flicker-free display; as a result, the frame rate is greater than would be required to depict motion adequately. In the proposed space color television system, the frame rate for motion depiction can be set independently from the frame rate required to avoid flicker in the display. This can be done because the proposed system uses scan conversion, and display flicker is determined solely by the output standards of the scan converter. The output standards in this case are those of television broadcasting, and are therefore adequate to eliminate flicker.

A form of bandwidth compression studied by Hughes Aircraft Company was considered carefully for possible inclusion in the system. A demonstration film was obtained and run several times for the group of engineers assigned to the color study. The Hughes method achieves a bandwidth saving by exchanging bandwidth for frame rate; a form of multiple dot interlace is used on a 256-line picture to secure frame rates as low as 2 per second (approximately). The method achieves the desired end for stationary objects, at least so far as the film record indicated. However, for moving objects it produces objectionable smear. The smear is a function of the distance that the object moves during the extended period of frame time provided by the multiple dot interlace. This smear seriously compromises the ability of the system to reproduce motion acceptably.

A copy of a paper by M. W. Baldwin entitled "Effects of Using Frame Storage in Television Transmission" was obtained from Bell Telephone Laboratories. The paper was illustrated by a motion picture film, which showed the effect of different motion frame rates while the flicker frequency is kept constant. The film showed a variety of subjects, including a close view of a man telephoning, a baseball game, an express train, a slow-moving steam locomotive, and two people walking into a room. Frame rates of 4, 6, 8, 12, 16, and 24 were used.

This special film was made from short clips of standard 24-frame-per-second 16-millimeter motion picture film. The various frame rates were obtained by special printing. For example, a film with a rate of 4 frames per second was made by using every sixth frame of the original film. Each of the selected frames was printed six times; the special print so obtained was run through a standard 16-millimeter 24-frame-per-second movie projector. The action rate in the scene was normal (though jerky) and the flicker rate was the normal 48 cycles per second. This method was referred to as "sample and hold". For a motion rate of 6 frames per second, every fourth original frame was selected and printed four times; the other motion frame rates used were obtained in a similar manner.

The film contained a section that had 6 motion frames per second and repeated the same subject material, but was processed by two different methods substituting for the "sample and hold." One of these methods is called "average and hold"; the other is called "dissolve". In "average and hold" processing, a group of four successive frames on the original film is averaged by superimposing them to form a frame of the test film; this frame is then printed four times. Each frame so printed was smeared due to the motion which took place in the scene over the time interval spanned by the frames in the original film.

For the section using the "dissolve" method, the same process involving four of the original frames was used, but the contribution of the first and fourth frames of the group of four was reduced so as to produce a "dissolve" effect.

In viewing this film, the "average" and "dissolve" processes were definitely found to be much inferior to the "sample and hold" processing. The eye preferred to be presented with a succession of sharp images rather than with a succession of unsharp pictures. The smear presented by the "average" and the "dissolve" processing was found to be objectionable. The "average" process generally resulted in pure smear, which was somewhat less objectionable than "dissolve", which produced multiple images in addition. With respect to the motion frame rates shown with "sample and hold", the consensus of the group was as follows:

(1) Twelve frames per second was satisfactory for most scenes;

(2) Eight frames per second was usually satisfactory;

(3) Six frames per second was often acceptable; and

(4) Four frames per second was usually unsatisfactory.

Both the Hughes film and the Bell film showed that smear is very objectionable; while the Bell film added the information that a succession of sharp pictures is definitely preferable to "averaged" pictures in depicting motion at low frame rates.

c. TWO-COLOR SYSTEM

Another method of effecting bandwidth economy is through the use of a two-color system. The concept of achieving color pictures using only two primaries has received considerable attention in recent years. This interest is to a great extent due to Dr. Edwin H. Land's work in the general field of color perception. How this work related to color television can best be summarized by an excerpt from a paper entitled "The Effect on Color TV of Dr. Edwin H. Land's Color Experiments" by Charles J. Hirsch, Chairman, EIA Broadcast Television Systems Committee as follows:

> "Dr. Land's experiments were repeated, under controlled conditions using photographic and television techniques, in several of the best-known color laboratories by scientific personnel experienced in colorimetry, color photography, and color television. Identical scenes were reproduced by Land's methods and by three-color techniques and compared.

In general the experimenters agreed that the effects described by Land exist and can produce pleasing color pictures, but these are quite limited in their gamut of possible colors when compared with the same pictures produced by three-color processes. They also agreed that these effects can be explained and predicted by existing color theory.

When red and green separations were projected respectively with red and white light, flesh tones were good but no saturated blues or greens were produced. The sky and grass tended to have the same desaturated blue-green appearance. Yellow was visible to some observers but only in small areas. Yellow was not visible in large areas, such as dresses, which looked pink to most observers. There were no magentas.

All hues can be produced by Land's methods by preselecting the colors of the two separations and the colors of the projecting lights to fit the desired results. Thus, magenta can be produced if one light is green. It is not possible to produce all hues, let alone chroma and value, from a single pair of color separations and a single pair of projection lights."

In examining the application of color television to space, it appears that in most all cases, there will be scientific interest in the color fidelity of the reproduced image of the scene as well as in the presentation of a color picture to the viewer. For this reason it appears that the pursuit of two-color systems should be relegated to those applications where the color television is used to enhance a remote control operator's perspective of the scene or a similar application where color fidelity is not important.

Two-color displays may be useful for space applications where color fidelity is not critical and the three-color display is not competitive because of size, weight, and power.

9. Discussion

a. APPLICATIONS OF SPACE COLOR TELEVISION

The space color television system should have the capacity for taking three basic types of picture. These types are defined as follows:

(1) Real time television pictures capable of portraying motion acceptably;

(2) Snapshot television pictures capable of freezing motion satisfactorily; and

(3) Still television pictures of stationary objects.

Pictures of type 1 require that a compromise be taken between resolution and frame rate, since the available bandwidth is limited. These pictures will have to be compatible with scan conversion to broadcast standards. Pictures of types 2 and 3 will have to be of the highest resolution possible within the limit set by the camera tubes. To this end, the frame rate must be reduced sufficiently to obtain a picture (of the desired resolution) that can be transmitted within the 1.25-Mc band available. Type 2 pictures will require a shutter to give an exposure time short enough to reduce motion smear to an acceptable level without reducing the sensitivity below a useful level. Three camera tubes (or suitable target-area sharing on a single tube) will be required to enable the three separation images to be exposed simultaneously in order to avoid color fringing on moving objects. The requirements for type 3 are less severe than for the others, because the image contains no motion and the camera can be operated in an open mode without degradation due to smear or color fringing, even with the field sequential camera.

The study of the NASA space color television camera has resulted in one cardinal conclusion:

> "Registration of the color images should be a ground station operation."

This premise has had a major effect on the course of the study. The justification for this position is as follows:

(1) Operating experience with studio color cameras has shown that this equipment requires daily adjustment.

(2) Designing the necessary stability into the camera head would increase the power and weight of the flight equipment. The long-term stability and environmental stability requirements for the space application are considered to be compatible with the state-of-the-art.

(3) Correcting misregistration on the ground provides a decided improvement in the reliability of the overall system.

(4) The facility for registration on the ground would be included as a necessary part of most scan conversion techniques considered; therefore, it would not add to the overall system complexity.

(5) This decision allows a choice of dot, field, or line sequential approaches to the system problem.

On the negative side, it tends to make less attractive any other approaches such as the 4-tube separate-luminance-channel camera. The 4-tube system would require an additional subcarrier for the extra channel, but it is a scheme that tends to relieve the need for maintaining accurate registration of the three color rasters.

b. SELECTION OF SYSTEMS FOR THE VARIOUS APPLICATIONS

(1) Field Sequential System

Although a field sequential camera would adequately fulfill the requirements of type 3, it is not satisfactory for type 2, unless a three-tube version is used. A single-tube field sequential camera cannot be shuttered; therefore, smear and color fringing would occur. With the slower frame rates required for type 2 pictures, the color fringing problem of a single-tube field sequential camera would indeed be severe. Moreover, it would be unsatisfactory for type 1 service, because there is no way to avoid color fringing of motion pictures with the single tube camera. While it might be possible to devise a camera in which the color field time for red, green and blue are unequal (so as to take advantage of the lesser resolution requirements for blue and red as compared to green), a high degree of optical, mechanical, and electronic sophistication is required to achieve it. Even if such a camera could be developed, color fringing could not be avoided on motion. The only possibly satisfactory arrangement for a field sequential camera is one which uses three tubes, one for each of the three colors; the colors share the total frame readout time unequally on the basis of the resolution required for each; and a shutter is used to prevent color fringing of motion. The shuttering would reduce the sensitivity; however, while any shutterless camera will suffer from smear, a field sequential camera would also suffer from color fringing in the smeared area. A rainbow trail left by moving objects would unquestionably be far more objectionable and more noticeable than the smear. (This effect was evident during observation of field sequential tests that were held during the search for a suitable system for broadcast color television.) The effect would be worse in the space color television system because of the slower frame rate.

(2) Dot Sequential System

Systems of the dot sequential type (this term being intended to include all those systems which are variants of the NTSC standards and which were considered for space color applications) offer economy in the utilization of bandwidth. However, due to the constraint that image registry will not be carried out in the spacecraft, use of the true NTSC standards is not possible. In turn, this restriction prevents one of the major NTSC advantages from being adopted; namely, that of a color carrier which vanishes on white. Thus, there will be a problem imposed by the presence of color carrier over the whole picture area; of course, this condition can be alleviated, or perhaps avoided completely, by the use of a comb filter. Repcrts on broadcast service in France using SECAM, which employs a continuously present, frequency-modulated color carrier have indicated problems with subcarrier visibility. A further disadvantage of a color carrier which does not vanish on white can be seen by examination of System C, which has two subcarriers with a difference frequency of about 250 kc. This frequency is within the monochrome video band, and would impose a requirement for extremely linear transmitter modulation characteristics if a 250-kc beat is to be avoided. Such a beat, if produced, would have to be 36 db below the monochrome to be invisible, imposing a very stringent requirement upon transmitter and amplifier linearity.

A further disadvantage of the dot sequential system (in the forms considered for space color application) results from the necessity of sharing the available transmitter modulation characteristic between the monochrome signal and the subcarrier. System C has two subcarriers, each of which must subtract from the swing available otherwise for the monochrome signal; also, the available usable length of modulation characteristic may be further reduced by the necessity of staying upon the most linear part of it to avoid beat signals. The effect of this limitation is to reduce the signal-to-noise performance.

It appears that the advantage of more-efficient bandwidth utilization admittedly possessed by the dot sequential system would be outweighed by the problems arising from the presence of the subcarrier.

(3) Variable-Line Sequential System

The line sequential system, on the other hand, has some very interesting advantages. Because of the short interval of time between the scanning of corresponding elements of the three color separation images (260 μsec as compared to 44,000 μsec for a typical unshuttered field sequential system), color fringing is avoided even with open shutter operation. The system provides readily for the proper apportionment of resolution between red, green, and blue. Smear is no worse with open shutter operation than in any of the other systems considered and shuttered operation is perfectly feasible if necessary. In fact, it would present no problem to provide for shuttered or open shuttered operation at will. Of course, this capability can be provided in other systems, except the single-tube field sequential. It is therefore proposed that a variable-line sequential system of the type described above be chosen for type 1 use (realtime, motion portrayal). A more detailed discussion of this system follows.

c. DESCRIPTION OF VARIABLE-LINE SEQUENTIAL SYSTEM

The basic system parameters are listed in Table 3. The number of scan lines has been chosen at 512*, which corresponds to 2^9, making it possible to use a simple set of binary counters to derive the frame rate. This number of lines corresponds to a horizontal deflection rate of 3840 cps. In anticipation of the use of sync bursts, the master oscillator frequency from which the sync bursts are gated is set at 2^8 times the horizontal deflection frequency, which is equal to 983040 cps.** The tabulation gives the time periods associated with significant functions, to the nearest microsecond. It is intended that the basic master oscillator period of 1.017 microseconds be used as the standard timing interval for the system; thus the horizontal blanking is 32 units, the front porch is 4 units, and so on. The intercolor blanking is intended to mark the separation between the green video (which occupies the first segment of the signal generated by a scanning line) and the red or blue signal which follows it. The color line identification pulse designates the beginning of the scanning line which contains the blue video.

---

* It may be desirable to use 525 scan lines for certain scan conversion systems.

** It may be desirable to make the burst frequency an odd multiple of one-half the line frequency to facilitate sync separation.

TABLE 3. PARAMETERS OF VARIABLE-LINE SEQUENTIAL COLOR TELEVISION SYSTEM

Parameter	Value
Number of lines	512
Frame rate f_r	7.5 frames per second
Line rate f_h	3840 cps
Line period t_h	260 μsec
Line period active t_{ha}	223 μsec
Horizontal blanking period	33 μsec
Intercolor blanking	4 μsec
Vertical blanking (16 lines)	4170 μsec
Active time, green t_{hag}	167 μsec
blue t_{hab}	56 μsec
red t_{har}	56 μsec
Master oscillator frequency	983040 cps
Front porch (horizontal)	4 μsec
(vertical)	130 μsec
Back porch (vertical)	130 μsec
Sync signal horizontal burst (0.98 Mc)	8 cps
Color line identification pulse (0.98 Mc)	4 cps
Sync signal vertical bursts (0.98 Mc) (8 used)	128 cps
Video bandwidth	1.25 Mc
Horizontal resolution (Green)	320 TV lines
(Red and Blue)	107 TV lines
Vertical resolution (Green)	350 TV lines
(Red and Blue)	175 TV lines

The horizontal synchronizing pulse consists of a group of eight cycles of the master frequency. Its amplitude spans the full signal range between black and maximum luminance. For the scan lines containing blue, a second burst sync signal is transmitted, commencing 8 microseconds after the end of the horizontal sync burst; this second burst contains 4 cycles of the 0.98-Mc master frequency.

The vertical synchronizing signal also consists of bursts of 0.98 Mc but each burst contains 128 cycles, and there are eight such bursts spaced one line period apart. Each of the eight bursts starts at the time when a horizontal sync signal is due. In this way, the bursts serve to maintain horizontal sync (by suitable processing) in addition to vertical sync.

The composite video-sync waveforms are shown in Figures 14 and 15. Figure 14 shows two successive scan lines of the green field; each scan line has a secondary section as shown, giving respectively the video signal for blue and red. The active time within the scan line devoted to green is 167 microseconds, while that for blue or red is 56 microseconds. There is a brief intercolor blanking period of 4 microseconds to provide separation, and to aid in setting registry at the ground receiver. Horizontal blanking is 33 microseconds and part of this interval is devoted to transmission of the sync burst, as indicated. Other important timing information with respect to the waveform is shown. Figure 15 shows the details of the vertical blanking interval and the relationship of the vertical and horizontal sync bursts in that interval. The timing of all waveforms in the sync and blanking system is such that each can be obtained by simple binary counts from the master oscillator.

The problem of line crawl was a basic difficulty with the original line sequential system as proposed for broadcast service. The basic cause of this crawl was the regular cyclic variation of color of the scanning lines, which the viewer's eyes were required to integrate, but which in practice did not happen. The present proposal is not intended to provide a direct display, because the low frame rate would cause intolerable flicker. Instead, storage of the received image is provided to allow scan conversion. This storage will eliminate the problem of line crawl.

10. Summary and Conclusions

The line sequential system has been shown to possess characteristics which are well suited to the application of providing real time television pictures that will portray motion acceptably. The separation of motion frame rate from television frame rate brought about by scan conversion provides a display operating at television broadcast standard frame rate, and thus free of flicker. The

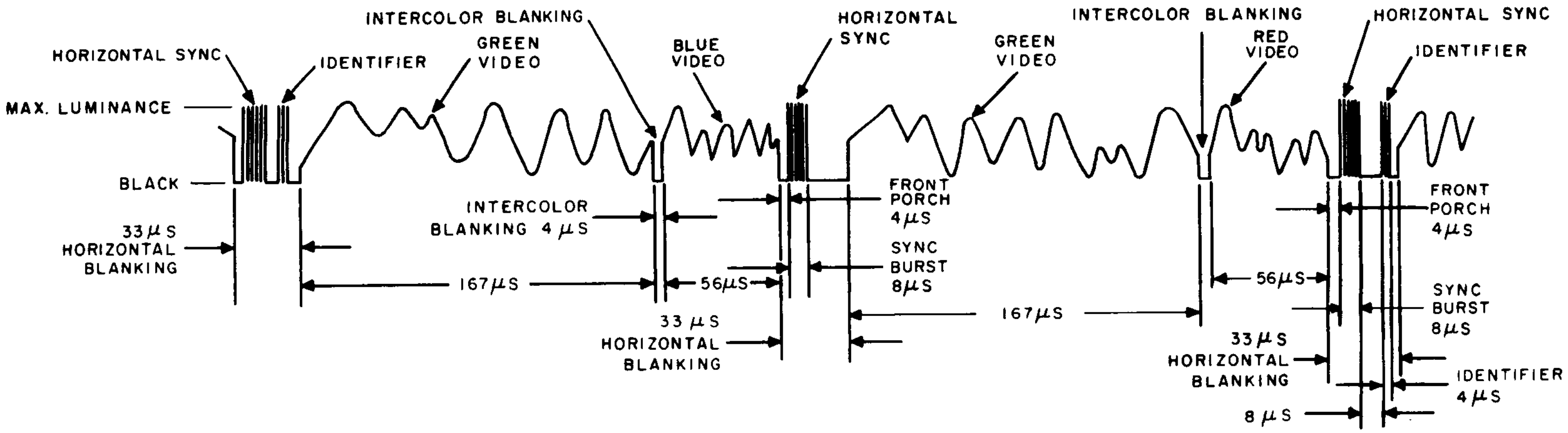


Figure 14. Composite Video Signal for Two Scan Lines

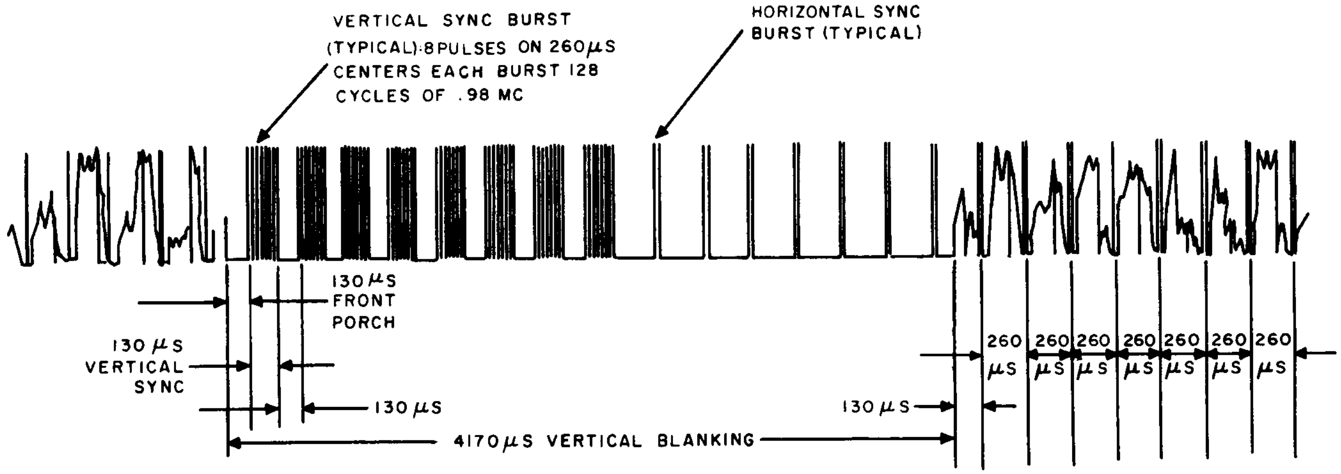


Figure 15. Vertical Sync and Blanking Signal

camera would contain three tubes, in a conventional-beam-splitter and trim filter arrangement, and would be capable of excellent colorimetry. The construction of such a camera is well within the present state-of-the-art. As a possibility for future development, particularly with the object of reducing camera bulk, the construction of a two-tube camera, using a striped filter for red-blue color separation on one tube, and a green filter on the other tube, presents an interesting possibility. The optical system of the two-tube camera may require some development work. In conclusion, it is recommended that the variable-line sequential system, as described and specified in this report, be adopted as the standard for realtime television pickup. It is also considered that the same line sequential system with a shutter, is the optimum choice for snapshots. The still picture requirement is best served by a single-tube frame sequential camera with a manually indexed filter mechanism and mounted on a tripod or equivalent.

B. COMMUNICATION SYSTEM

1. Communications Requirements

The communications system is required to provide a reliable r-f link with adequate system margin for communications from manned spacecraft to earth. The particular down-links that were studied are:

(1) Near-earth orbits

Gemini-Agena spacecraft in a 300 nautical mile orbit to ground stations with a 16-foot or a 30-foot antenna.

Apollo spacecraft in a 300 nautical mile orbit to ground stations with a 16-foot or a 30-foot antenna.

(2) Far-earth missions

Apollo spacecraft in lunar orbit to MSFN* ground stations.

LEM capsule on the lunar surface to MSFN ground stations.

(3) Apollo applications

Missions that afford wider video bandwidths and have more power available.

(4) Relay of near-earth video transmission to MSFN via communication satellites.

2. System Constraints and Assumptions

The significant constraints and assumptions listed in the following paragraphs were used by the study program to determine system parameters and performance, to evaluate the down-links, and to arrive at their resultant recommendations.

---

* Apollo Manned Space Flight Networks

a. CONSTRAINTS

(1) Near-earth

(a) A circular orbit with an altitude of 300 nautical miles.

(b) A maximum r-f power of 20 watts.

(c) The availability of sufficient d-c power for the r-f power.

(d) The receivers and ground antennas available are:

Antenna Diameter (feet)	Receiver (f-m)	Frequency (Mc)	IF Bandwidth (Mc)	Antenna Gain (db)	Noise Figure (db)
16	N. American	1710	20	36	4
30	Worldwide	2272.5	5	44	2

(e) The Gemini-Agena equipment should be ready for integration by November, 1966 and the Apollo equipment by November, 1968.

(2) Far-earth

(a) A maximum r-f power of 20 watts.

(b) The availability of sufficient d-c power for the r-f power.

(c) The r-f spectrum of the allocated television channel is constrained to 5 Mc in the 2.2-Gc band.

(d) The receivers and antennas available are:

Antenna Diameter (feet)	Receivers (f-m)	Frequency (Mc)	IF Bandwidth (Mc)	Antenna Gain (db)	Noise Figure (db)
85	Worldwide	2272.5	5	52	2
85	MSFN	2272.5	1, 4, 8.5	52	1.7

(e) The Apollo equipment should be ready for integration by November, 1968.

b. ASSUMPTIONS

(1) For near-earth missions, the desirable $\frac{\text{peak-to-peak video signal}}{\text{rms noise}}$ is 40 db.

(2) Near-earth missions should be able to maintain communications when the ground antenna has a minimum elevation angle of 5 degrees. Utilization of the MSFN receiver will be considered as well as the N. American and Worldwide units.

(3) For far-earth missions, the acceptable $\frac{\text{peak-to-peak video signal}}{\text{rms noise}}$ is 32 db.

(4) For Apollo and LEM missions, the engineering design effort should strive for minimal addition or modification to the Unified S-Band (USB) equipment in order to conserve weight and power on the spacecraft.

(5) The recommended color transmission system is variable-line sequential with a video baseband of 1.25 Mc for each color. Link parameters for the variable-line sequential system and the pseudo-NTSC scheme* are tabulated in this section.

3. System Considerations

a. VARIABLE-LINE SEQUENTIAL SYSTEM

The basic communication system for the line sequential color scheme is shown in Figure 16. In contrast, the more complex block diagram for the pseudo-NTSC scheme* is shown in Figure 17. However, this portion of the study is primarily concerned with the link between points 1 and 2 of Figure 16.

In the recommended variable-line sequential scheme, output of the camera electronics is applied to the premodulator processor, which essentially controls the amplitude of the color video signals. These signals are then used to modulate the f-m exciter whose output is amplified and delivered through suitable filters to the spacecraft antenna for transmission. (The video spectrum is recovered at the ground stations within the power and bandwidth contraints of Paragraph B 2a.) The line sequential scheme eliminates the need for subcarrier modulators, vestigial sideband filters, separation filters, and subcarrier demodulators.

---

*System C described in Section IIA.

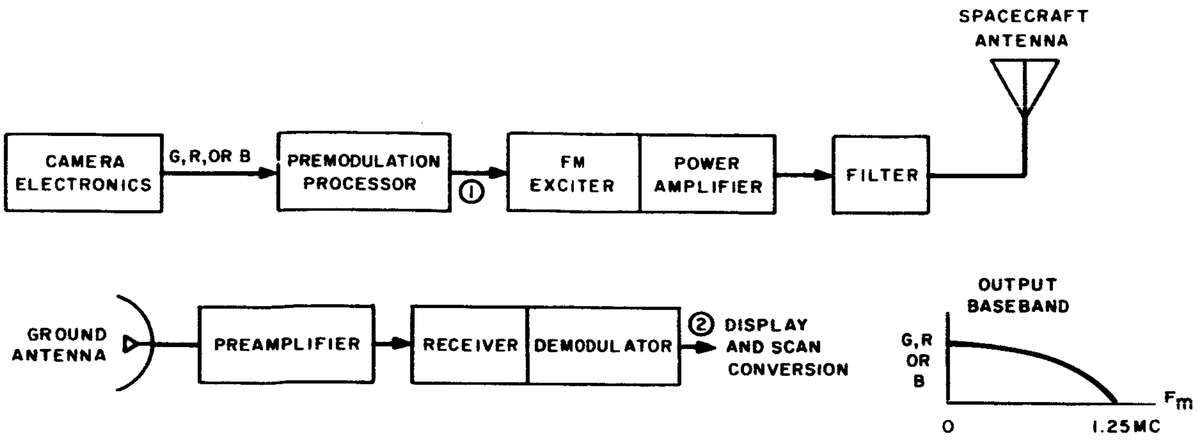


Figure 16. Recommended Line Sequential System, Block Diagram

b. CHOICE OF MODULATION METHOD

It is important to select a modulation method that affords adequate r-f margin and output signal-to-noise ratio (S/N) at the receiver for a given transmitter power output. The choice of a modulation technique should involve an uncomplicated design and also be one which affords compatibility with existing equipment.

For transmission of color television, in the missions considered by the study, the best modulation method is frequency modulation (f-m). It is a straightforward proven method, and existing hardware can easily be adapted to the required equipment within the time scale of the specified missions. When compared with amplitude modulation, frequency modulation affords S/N improvement. For Apollo flights, frequency modulation also permits consideration of utilizing the existing Unified S-Band (USB) modulator. Other methods of modulation do not show any significant features to change this choice. For example, single sideband-amplitude modulation (SSB-AM) is not acceptable because it requires a sharp cut-off filter which produces unavoidable phase shifts and resultant distortion of the TV signal. This method also has the disadvantage of requiring complex circuitry at the receiver. Pulse code modulation (PCM) requires a bandwidth which is comparable to f-m but requires additional components on the spacecraft; such as a quantizer and encoder, as well as complex terminal equipment. Therefore, frequency modulation has been selected on the basis of proven circuitry, USB compability, hardware availability, and S/N improvement.

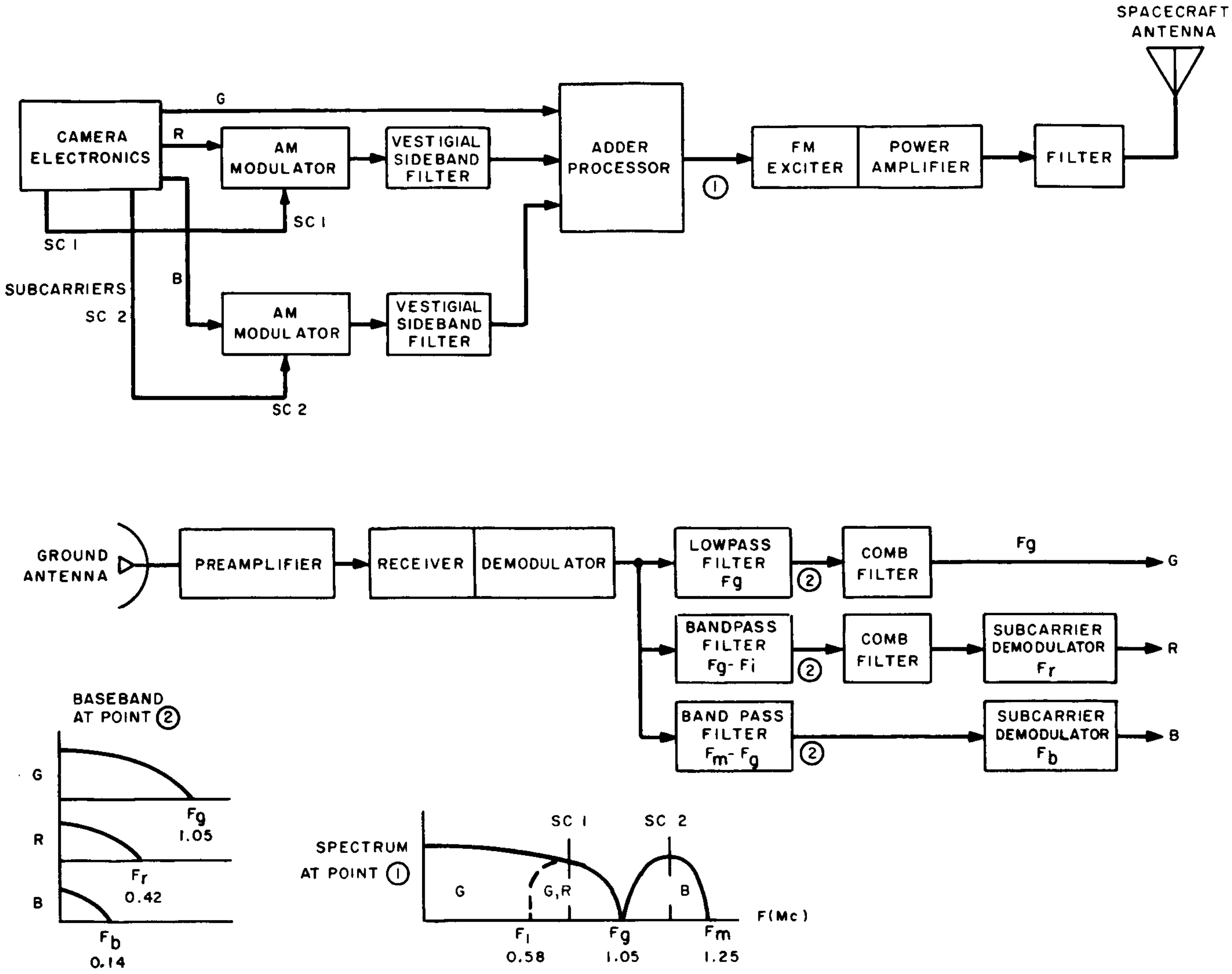


Figure 17. Pseudo-NTSC System, Block Diagram

c. LINK PARAMETERS

(1) R-F Margin

The r-f margin (M) is defined as the difference between expected carrier-to-noise ratio (C/N) at the receiver and the threshold value of its demodulator. It is implicitly assumed in this definition that the carrier threshold is the governing parameter which when exceeded makes a receiver operable. A substantial margin is desirable to provide for system deterioration and non-optimum conditions. The margin is required to compensate for a decrease in transmitter power output, deterioration of receiver noise figure, or slant ranges greater than expected.

The desirable amount of margin is a subjective matter. However, if all the expected degradations from each cause are known, the worst-case C/N can be calculated by using negative tolerances. Then the required amount of margin is no longer subjective, but becomes a definite value above the threshold level. In this study, tolerances for all link parameters are not known. The carrier-to-noise ratio was determined for near-earth missions using the minimum antenna elevation of 5 degrees. For far-earth missions the ratio was computed under the worst-case condition of bore-sighting the MSFN antenna with the moon's center. Since only some of the worst-case values of link parameters were known the amount of margin required remains subjective. According to Kuykendall*, the r-f margin for the monochrome television from LEM to MSFN is 2.3 db (an improvement of 2 or 3 db can be expected, if cooled parametric amplifiers are used).

In view of the foregoing discussion, this study assumed that an r-f margin of 3 db was acceptable.

(2) Bandwidth and Deviation

A constraint on the r-f spectrum, either by channel allocation or available receiver bandwidth, will affect the required deviation characteristics of the transmitter. Carson's rule can be used to approximate the required information bandwidth for f-m as follows:

$$B_i = 2\ (F_m + F_d) = 2\ F_m\ (1 + \delta) \tag{1}$$

where, F_m is the highest modulation frequency (baseband)

F_d is the maximum transmitter deviation

δ is $\frac{F_d}{F_m}$, the deviation ratio

In this study, since the values of δ are quite small, the significant sidebands and maximum δ were determined directly from curves of Bessel coefficients rather than using Carson's rule. This more exact method resulted in a larger value of F_d so that the output signal-to-noise ratio (S/N) of the receiver is optimized within the bandwidth constraint.

*W. Kuykendall, NASA/MSC, "LEM Unified S-Band System." Proceedings of Apollo USB Tech. Conference, GSFC, July 14-15, 1965: NASA SP 87

The analysis of bandwidth and deviation for the line sequential scheme is straightforward since only one color baseband modulates the transmitter at a time. In the pseudo-NTSC scheme (System C), the green baseband plus the red and blue subcarriers modulate the transmitter simultaneously. In this case the peak deviation of the transmitter is the sum of the deviations of each color signal. The criterion for choosing the deviation ratio for each color in the pseudo-NTSC system is that the output S/N ratio for the green, red, and blue signals is 59:30:11, respectively. These proportions are the same as the luminance (Y) signal content in commercial color television, and they are also the approximate ratio of the color baseband at point 1 in Figure 17. Signal-to-noise ratios listed in Table 8 for the pseudo-NTSC scheme (System C) apply only to the green (G) signal. The S/N ratio will be 3 db less for red (R), and 7.8 db less for blue (B).

(3) Signal-to-Noise Ratio

The signal-to-noise ratio (S/N) of the color signal at the output of an f-m receiver, point 2 of Figure 4 is determined from:

$$(S/N)_{FM} = \frac{3}{2} \frac{F_d^{\,2} B_{IF}}{(F_u^3 - F_1^3)} \tag{2}$$

where, $(S/N)_{FM}$ is the $\frac{\text{rms signal power}}{\text{rms noise power}}$;

C/N is the $\frac{\text{receiver power in } B_{IF}}{\text{noise power in } B_{IF}}$;

B_{IF} is the receiver i-f bandwidth;

F_d is the peak deviation of the r-f carrier; due to the color signal;

F_u is the upper band edge of the color video spectrum; and

F_1 is the lower band edge of the color video spectrum.

For the line sequential scheme, the expression becomes:

$$S/N = C/N \; 3\delta^2 \frac{B_{IF}}{2 F_m} \tag{3}$$

In the pseudo-NTSC case (System C), expression (2) applies to each color. In Figure 17, the red and blue subcarriers are demodulated by a-m detectors so that output S/N for each color is:

$$(S/N)_G = (S/N)_{FM} \quad (4.1)$$

$$(S/N)_R = (S/N)_{FM} \; M^2 \; \frac{(F_m - F_g)}{2F_b} \quad (4.2)$$

$$(S/N)_B = (S/N)_{FM} \; M^2 \; \frac{(F_g - F_1)}{2F_r} \quad (4.3)$$

where M is the a-m modulation index and is assumed to be 90 percent for tabulated values.

The output S/N calculated by the above expressions is equal to $\frac{\text{rms signal power}}{\text{rms noise power}}$. The ratio of peak-to-peak signal to rms noise is considered to be 9 db greater than this calculation.

For a composite video signal employing conventional sync, the peak-to-peak video signal is 2.5 db less than the peak-to-peak signal when 25 percent of the composite video is allocated for sync information. By utilizing a sine-wave burst as the synchronizing signal, the peak-to-peak video signals equals the peak-to-peak signal. This type of sync, therefore, overcomes the 2.5 db loss due to conventional sync. In effect, full deviation of the transmitter can be utilized by video so that receiver S/N is enhanced. A distinction has been made in the basic assumption (Paragraph B2b) between the acceptable and desirable S/N output of the receiver. The acceptable S/N applies to far-earth missions which are limited in both power and bandwidth.

4. Hardware Considerations

a. POWER SOURCE

The Gemini-Agena mission (and others) requires a separate transmitter for color television due to the absence of suitable equipment. To obtain the required 20 watts of r-f power in the spacecraft, microwave tubes should be used rather than solid state devices. The required delivery schedule of the Agena hardware eliminates consideration of solid state devices, and it is, also, doubtful that they could deliver half of the required power at a competitive efficiency. Efficiencies of present day varactor chains can be expected to increase with future development, however, solid state gains will be offset by tube improvements. Therefore, the following S-band power amplifiers were considered.

(1) Amplitrons

(2) Triode cavity amplifiers (TCA's)

(3) Electrostatically focused klystrons (ESFK's)

(4) Traveling wave tubes (TWT's)

(1) Amplitron

The amplitron is a device with an estimated life of 10,000 hours. A redundant Amplitron power amplifier is currently being developed for LEM. In life tests conducted by that program, the tube has shown a tendency to lose Gauss-line lock and actual tube life has not exceeded 1500 hours. No amplitron has been space-qualified to-date. This tube cannot, therefore, be recommended for any of the missions covered by this study except conditionally and subject to future qualification.

(2) Triode Cavity Amplifiers (TCA)

Triode cavity amplifiers were considered because they are available at the desired frequency and power level. However, their principle disadvantage is poor efficiency. Tube efficiencies of 23 percent can be expected at the 20-watt power level. Package efficiency decreases to 20 percent when used with an 89 percent efficient power supply. Since, only a 10 db power gain can be realized, a 2-watt driver is required. If the efficiency of the driver is assumed to be 25 percent, then the efficiency of the high-power stage is lowered to 19 percent. Therefore, because of poor efficiency this tube cannot be recommended.

(3) Electrostatically Focused Klystron (ESFK)

The best tube efficiency that this device has demonstrated is about 24 percent at the 20-watt level. If a power supply efficiency of 89 percent is assumed, then the amplifier efficiency is about 21 percent. However, the ESFK has several advantages. It requires less external filtering since it is a narrow band device. The second harmonic content of an ESFK is about

30 db below the fundamental, which represents a 20 db improvement over a TWT. Noise figures of both the ESFK and the TWT are comparable, and both are reported to be at least 20 db better than amplitrons at the 20-watt level. Despite its apparent advantages, the ESFK is not recommended for missions considered by this study because of its low efficiency and also because it is still in the early prototype development stage.

(4) Traveling Wave Tubes (TWT)

From the viewpoint of demonstrated spaceborne reliability and availability, the traveling wave tube (TWT) is superior to all other devices. A 20-watt unit has been qualified for Apollo and is considered in the survey of Table 4. This tube presently has a minimum efficiency of 30 percent. When coupled to an 80 percent efficient power supply, amplifier efficiency becomes 24 percent. The requirements for an r-f driver are minimal as the TWT gain of 27 db necessitates only 40 milliwatts of drive power. Broadband noise characteristics of a TWT are as good as the ESFK. However, a 20-watt tube can be expected to produce from one to two watts of second harmonic power which will require adequate filtering. The TWT has a proven capability in space environment and no other tube can compete with it in terms of demonstrated performance and reliability. For this reason, whenever a 20-watt power amplifier is required in any particular link of this study, a TWT is recommended.

A survey of the power amplifier field indicates that in the next two years improved TWTs may yield tube efficiencies in the area of 50 percent, with overall TWT/power supply packages exhibiting efficiencies of 40 to 43 percent. Table 4 is a tabulation of existing amplifier packages. The perferred package is the Hughes Unit, model 394H, which is the same unit used on the Apollo program.

b. MODULATOR-EXCITER

Table 5 lists the hardware presently available as exciters in the 1.7 and 2.2 Gc bands. A combination of the Resdel, model 91072, exciter and the Resdel 2.5-watt cavity amplifier were used on the Pegasus satellite for wideband TV transmission. For this study, the power amplifier was considered to be extremely inefficient, and it should be replaced by a TWT with a much higher output. For the line sequential color scheme with a 1.25 Mc video baseband, the most efficient space qualified exciter is the Conic, model CTM-UHF4. It has the advantage of being an "off-the-shelf" item. It is designed to lock the transmitter frequency during vertical and horizontal synchronization intervals. However, the

TABLE 4. POWER AMPLIFIER PACKAGE CHARACTERISTICS

Company	Model No.	Amplifier Characteristics				Integrated Power Amplifier and Power Supply				Remarks
		Freq. (Gc)	Drive Power (mw)	Output Power (watts)	Gain (db)	DC Power (watts)	EFF. (per-cent)	Vol. (cu. in.)	Weight (lbs.)	
Hughes Micro-wave Tube Div. Los Angeles, Calif.	218 H 394 H	1.7 2.2	40 40	20 20	27 27	102 84	20 24	144 144	6.0 6.0	Fully qualified tubes used on present programs
Watkins-Johnson Palo Alto, Cal.	W-J274 —	1.7 2.2	50 10	20 20	26 33	78 60	26 34	192 75	8.0 4.2	Not qualified
Resdel Eng. Pasadena, Cal.	91064 —	1.7 1.7	175 2.5w	2.5 10-100	13 13	60	4.2 30			Not qualified Cavity amplifier
Energy Systems Palo Alto, Cal.	5000-TR5	2.2		20		196	10	223	12	Complete package qualified for use on Saturn. Uses Hughes 394H TWT plus an exciter.
RCA, Astro-Electronics Div. Hightstown, N.J.	A1292/ 4056	2.25	10	20 min.	34	82	24	192	9.7	10 watt TWTA, qual-ified; 20 watt TWTA not qualified, but same basic design

TABLE 5. MODULATOR-EXCITER CHARACTERISTICS

Company	Model No.	Freq. (Gc)	Freq. Stab. (%)	Modulation Bandwidth	Peak-to-Peak Dev. (Mc)	Power Output (watts)	D-C Power (watts)	Vol. (cu. in.)	Weight (lbs.)	Remarks
Resdel Eng. Pasadena, Cal.	91072	1.7	±0.005	60 cps to 6 Mc	12	0.175	45	150	6-3/4	All solid state. Space qualified on Pegasus satellite. Frequency locks on sync tips.
Conic Corp. San Diego, Cal.	CTM UHF-4	1.7 or 2.2	±0.005	D-C to 8 Mc	12	3.0	49	35	2	Space qualified for Saturn 1C. Frequency locks on sync tips.
Conic Corp. San Diego, Cal.	CTM UHF-3	2.2	±0.005	5 cps to 1 Mc	2.4	2.0	49	35	2	Space qualified.
Motorola Scottsdale, Arizona		2.2		20 cps to 0.8 Mc	3.0	2.5	65	65	4	Unit similar to USB modulator in approach, narrower modulation bandwidth.
EIMAC San Carlos Cal.	EM 4527	2.2	±0.002	5 cps to 1.2 Mc	3.2	2	20	55	4	Tunable triode cavity oscillator. Frequency lock on sync tip. Not space qualified.
EIMAC San Carlos, Cal.	EM 4567	2.2	±0.002	5 cps to 1.2 Mc	3.2	10	60	110	8	Not space qualified.
Alto Scientific, Palo Alto, Cal.	G-156	2.2	±0.05	10 cps to 7 Mc	10	9	75	400	13	Voltage tunable magnetron. Frequency lock on sync tips. Not space qualified.
Monitor Elec. Orange, Cal.	2250P2 FMTM	2.2	±0.005	5 cps to 0.5 Mc	1.0	2	30	57	3-1/4	Not space qualified
Energy Systems Palo Alto, Cal.	5000-TR-5	2.2	±0.05	5 cps to 8 Mc	18					Part of package shown in Table 4.

modulator must be modified if a sine-wave sync burst is to replace the conventional sync. This modification is considered to be a minor redesign by the manufacturer. As an exciter for the preferred TWT, power stages must also be modified so that output is reduced to 40 milliwatts. The required d-c power for the exciter with this modification is estimated at 13 watts.

c. UNIFIED S-BAND FM MODULATOR (USB-FM)

(1) Characteristics

One design objective is compatibility with the existing Unified S-band frequency modulation (USB-FM) modulator. The monochrome video signal is presently applied to an f-m modulator which is part of the Apollo or LEM transponder. A block diagram, of the significant blocks, for TV is shown in Figure 18. In the present TV mode of operation, monochrome video is summed with voice and telemetry subcarriers and routed to the f-m modulator. The modulator has a maximum bandwidth capability of 10 cps to 1.5 Mc, and a peak deviation capability of ± 3 Mc; although the latter capability is not fully utilized for monochrome TV. Two assumptions were made for operation with the color TV baseband. First, time-sharing of monochrome and color TV can be incorporated by video switching in the premodulation processor. Second, the full

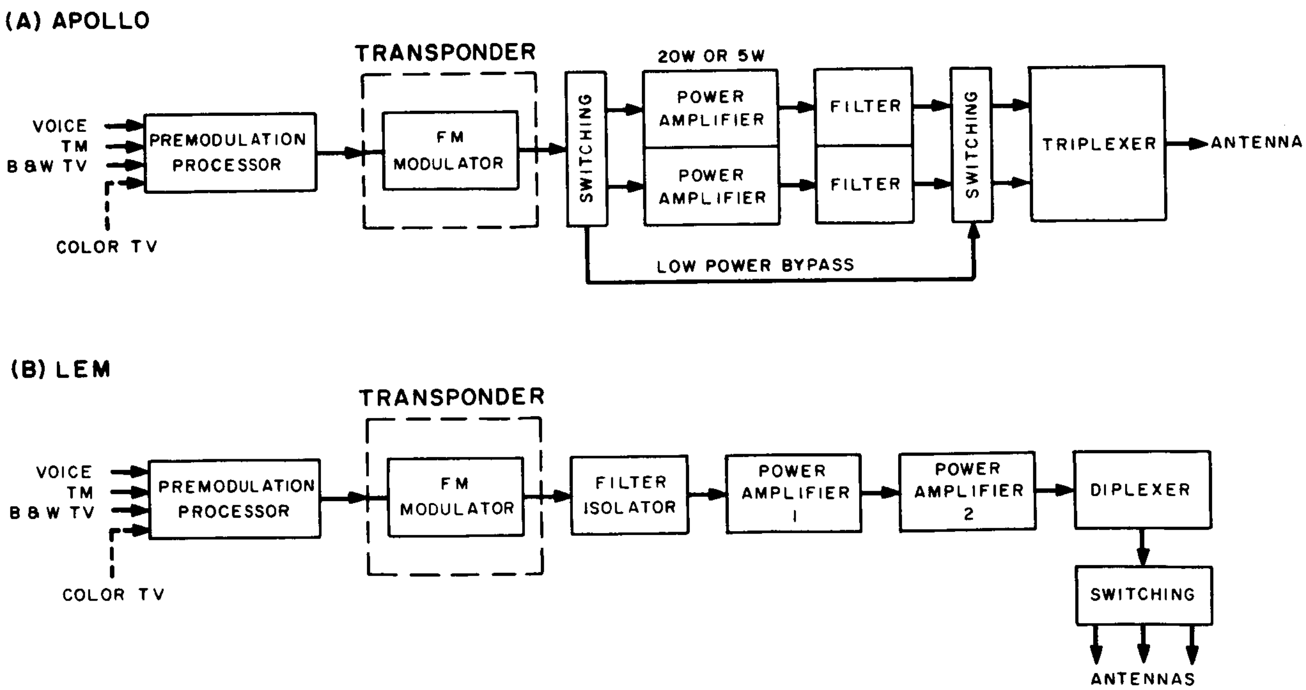


Figure 18. Unified S-Band Modulator and R-F Block Diagram

modulation bandwidth of the modulator can be utilized for color video, but in the color mode the voice and telemetry information can not be transmitted via the f-m carrier.

Other significant characteristics of the USB modulator are:

(1) Harmonic distortion is less than 1.5 percent.

(2) Stability at center frequency is specified as ± 0.0015 percent.

(3) According to the transponder manufacturer (Motorola, Scottsdale, Arizona), the f-m modulator performance is independent of the synchronizing waveform.

(4) Sensitivity of the modulator is designed to produce ± 1.5 Mc deviation from a 2-volt peak-to-peak input signal.

In the pseudo-NTSC color scheme (System C) the red, green, and blue signals require additional processing to control the deviation of the modulator by each color. This processing will require circuit modifications in the pre-modulation processor. Time-sharing of monochrome video with line-sequential color video will require less circuit modifications in the processor than the pseudo-NTSC.

(2) Considerations

The USB modulator is presently a-c coupled so that its center frequency corresponds to the average level of the input video signal. If the input is greater than 2-volts peak-to-peak, the modulator can be overdeviated when the average video is close to either the blanking level or the "white" level. This overdeviation will occur in a scene which has a "white" vertical bar on a dark background or visa versa. With a-c coupling the peak deviation must be limited to ± 1.5 Mc in order to allow for such a scene. By changing the modulator coupling to d-c, and clamping the blanking level to a fixed level the full frequency deviation capability can be utilized.

The low frequency response of the USB modulator is an important consideration since low video frequencies supply the background of the reproduced picture. Failure of a modulator or video amplifier to pass these frequencies in their original form will cause the displayed background to be non-uniform; that is, shaded in the vertical direction. Maximum non-uniformity in background conditions occurs when the scene is "half-black" and "half-white" about a horizontal centerline. Low frequency performance of the USB modulator can be evaluated by considering a square wave input signal at the field frequency. The amount of distortion can be analyzed if the coupling network and modulator transfer function are known. Although these coupling characteristics are not readily available, the effect of low frequencies upon the background can be illustrated.

Consider the low-frequency performance with the RC network shown in Figure 19 (A). The time constant, τ, and the 3 db cutoff frequency, f_c, are related by

$$f_c = \frac{1}{2\pi RC}, \text{ and } \tau = RC.$$

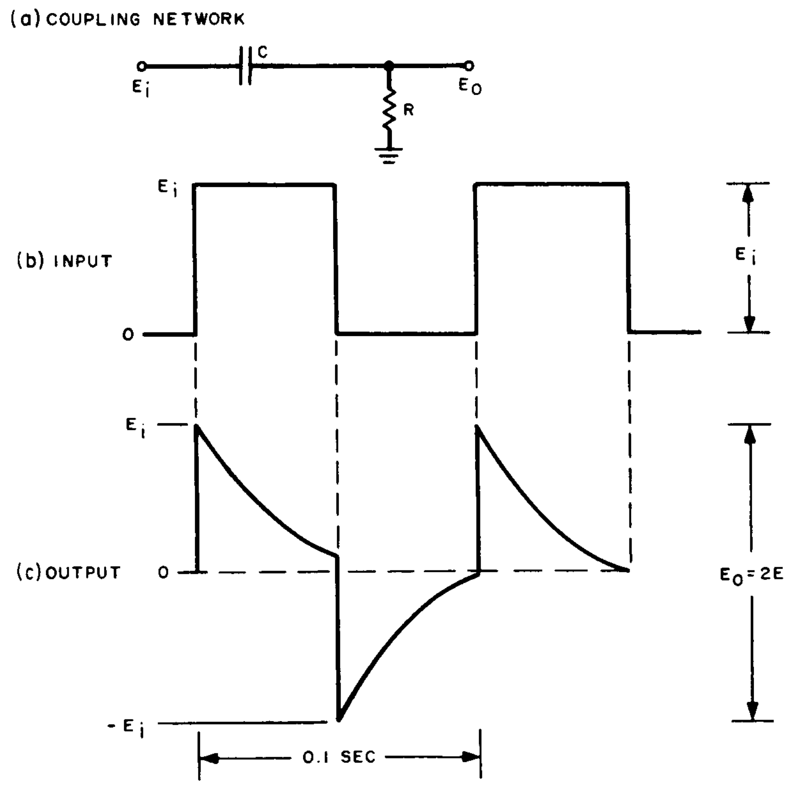


Figure 19. Low Frequency Performance

The RC network affects the 10-cps square wave shown in Figure 19 (B) so that it is differentiated as shown in Figure 19 (C). Response to a vertical step input is $E_o = E_i \, \epsilon^{-t/RC}$.

For a time, t, equal to half a field or 0.05 seconds, the amount of differentiation is 97 percent; or

$$\frac{E_o}{E_i} = 0.04.$$

The input square wave is distorted by the poor low-frequency characteristic of the RC network so that the peak-to-peak amplitude is essentially doubled. Overdeviation of the modulator can result, therefore, from inadequate response at low frequencies. The differentiation or shading effect calculated here is a worst-case example. In order to preclude this condition, the low-frequency response must be improved. In order to avoid overdeviation, the peak-to-peak input signal must be no greater than 2 volts. Although the actual network characteristics for the USB modulator are not available, the low-frequency response is expected to be significantly better than the example. In the calculations, the following assumptions are implicit for the conditions of full USB modulation deviation ($F_d = \pm 3$ Mc).

(1) The coupling is d-c with the video input clamped,

(2) The low-frequency response is adequate so that differentiation or shading is insignificant and over deviation does not occur.

d. MSFN RECEIVERS

A block diagram of the significant components for video reception is shown in Figure 20. Characteristics used in subsequent link calculation are:

Noise figure (parametric amplifier)	1.7 db
Predetection bandwidth, selectable	1, 4, and 8.5 Mc
Post-detection bandwidth	Highest modulating frequency.
Effective system noise temperature	320°K
Antenna size	85 ft. diameter
Antenna gain	52 db
Antenna beamwidth (half-power)	0.35 ± 0.05 degrees
Predetection required S/N*	10 db

The above predetection signal-to-noise ratio actually includes some margin. Demodulation is performed by a modulation tracking phase-lock loop (PLL) with a carrier-to-noise threshold of about 7 db.

* Spec. No. LSP-380-17, Table IV, "LEM to MSFN S-Band Communications Characteristics."

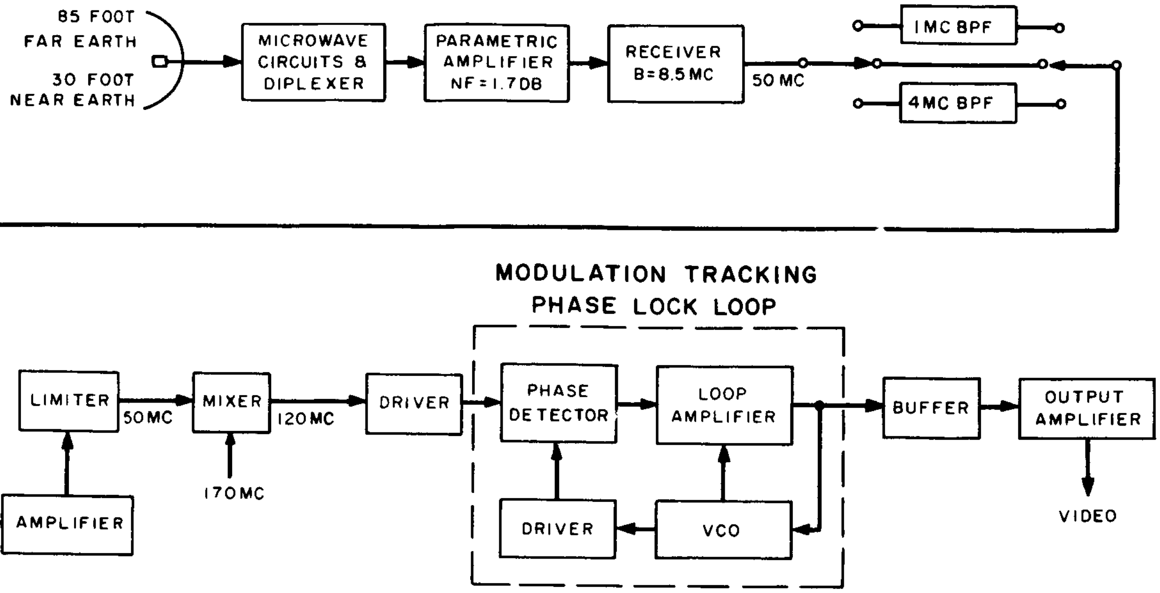


Figure 20. Basic MSFN Ground Station Video Reception, Block Diagram

e. NEAR-EARTH ANTENNA

The antenna considered in the link analyses, which follow, differ from present near-earth transmitting antennas. The present units have a minimum gain of 3 db, a null in the nadir direction, and are linearily polarized. The polarization and the null position are not deemed optimum for near-earth missions. A preferable unit is a flush-mounted spiral antenna or a wide-beam device similar to the feed used on the S-band antenna for Lunar Orbiter. The latter is shown in Figure 21. Achievable on-axis gain is 7 db with the typical pattern shown in Figure 22. Link performance with such an antenna is superior to the existing unit because of its higher gain, circular polarization, and coverage in the nadir direction.

The dipole-reflector antenna is fed by a 50-ohm coaxial transmission line which extends to the conventional slotted balun shown in Figure 21. The inner conductor of the coaxial feed line is shorted to one of the split legs at the mid-point of the balun. Orthogonal dipoles are fed from the balun. Dipole lengths are adjusted for equal magnitude currents in phase quadrature. The cone-cylinder reflector is positioned so that the crossed dipoles are in its aperture plane. This antenna generates equal E-plane and H-plane patterns which produce good circular-polarization over the beamwidth. Mechanically, the antenna configuration is strong and can easily withstand the launch vibrations and accelerations.

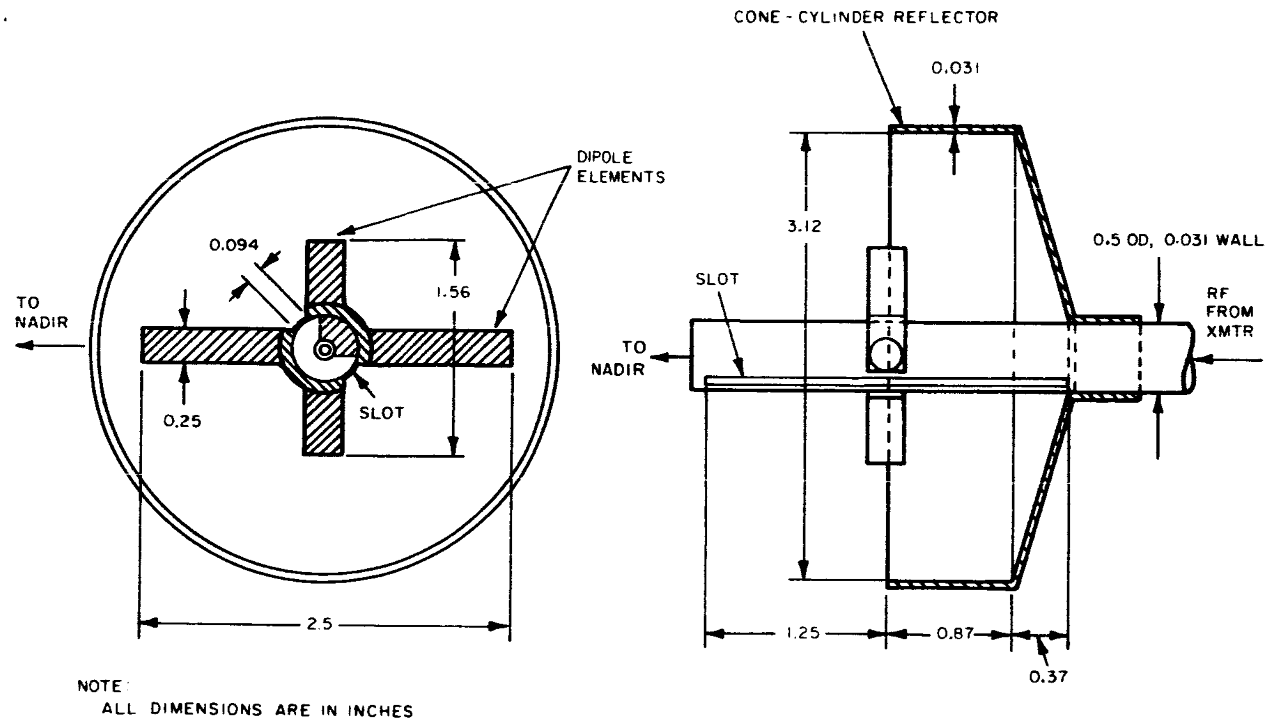


Figure 21. Preferable Near-Earth S-Band Antenna

5. Near-Earth Link Analysis

a. GEMINI-AGENA

(1) Received Power

A tabulation of link parameters for a near-earth mission is given in Table 6. Assumed transmitter power is 20 watts. Carrier-to-noise ratios are derived for the two near-earth receivers under the worst link geometry; namely, maximum slant range at a ground antenna elevation (Ψ) of 5 degrees. The near-earth antenna has been assumed to be that shown in Figure 21. Characteristics are included in Table 6 for the MSFN receiver based on the assumption that it is used with a 30-foot diameter ground antenna.

The "worst-case" carrier level (Ψ equal to 5 degrees) is below threshold only for the North American receiver. Received power increases rapidly with elevation angle as shown by Figure 23. This curve includes improvement due to higher gain of the spacecraft antenna at more favorable look-angles as well as improvement due to smaller slant ranges. Threshold is exceeded for the North American receiver when Ψ is greater than 10 degrees.

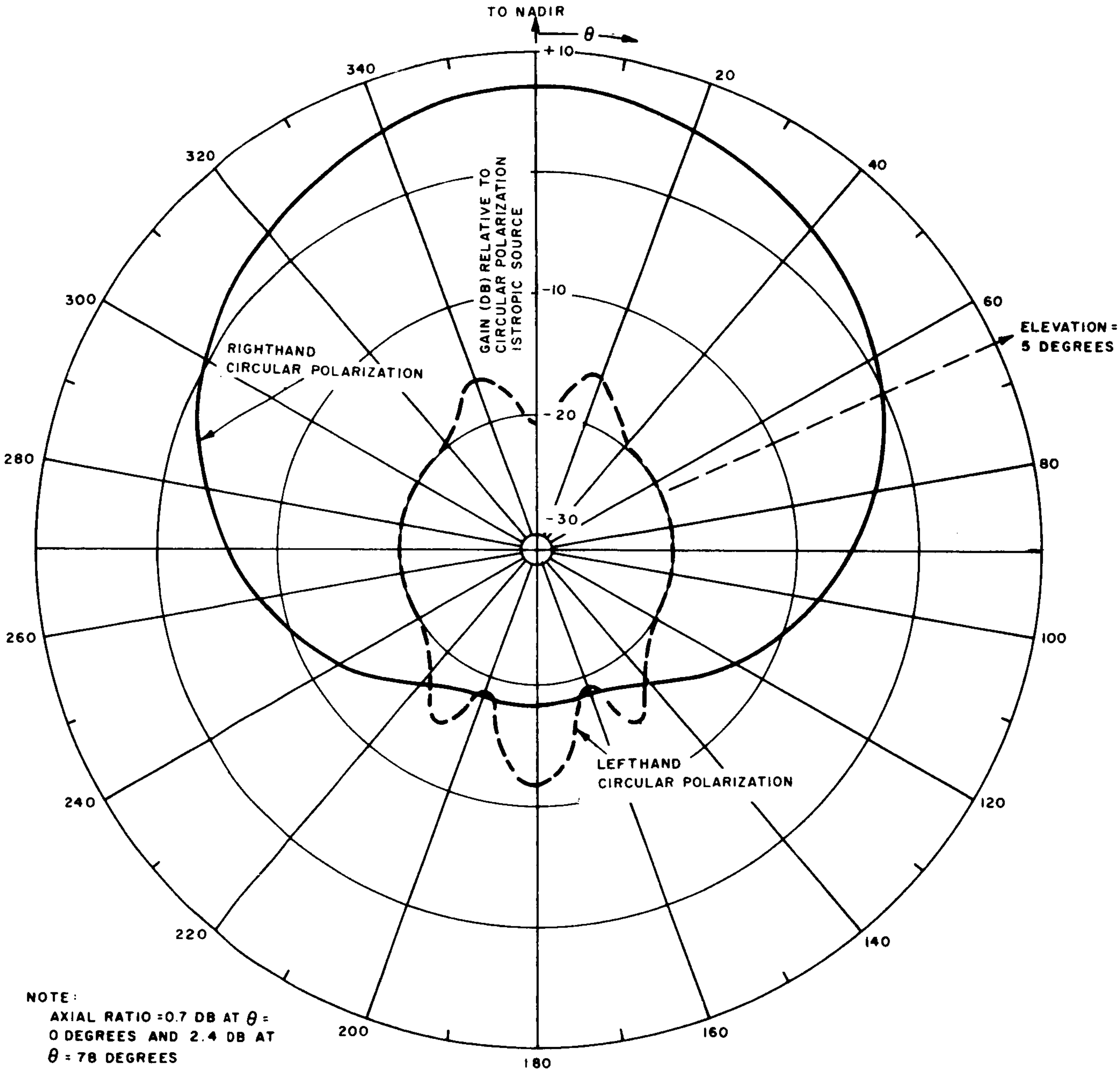


Figure 22. Near-Earth Antenna Pattern

(2) Bandwidth and Deviation

The carrier-to-noise ratios (C/N) tabulated in Table 6 are independent of the modulating bandwidth (F_m) and peak transmitter deviation (F_d). These parameters determine the information spectrum radiated, which must be smaller than receiver i-f bandwidth. Actually, information bandwidth

TABLE 6. NEAR-EARTH LINK PARAMETERS, GEMINI-AGENA

Conditions:

Altitude = 300 nautical miles
Antenna Elevations = 5 degrees
16-Foot Antenna for 1710 Mc
30-Foot Antenna for 2272.5 Mc

Receivers	F (Mc)	BW (Mc)	NF (db)
North American	1710	20	4
Worldwide	2272.5	5	2
MSFN	2272.5	8.5	1.7

Parameter	North American Receiver	Worldwide Receiver	MSFN Receiver	Comments
Losses:				
Path	-164.0 db	-166.5 db	-166.5 db	ψ = 5 degrees
Tropospheric	-0.2 db	-0.2 db	-0.2 db	
Polarization	-0.3 db	-0.3 db	-0.3 db	Circular to circular
Atmospheric	-0.5 db	-0.5 db	-0.5 db	
Line, Spacecraft	-1.0 db	-1.0 db	-1.0 db	TX output through antenna
Line, Ground	-0.5 db	-0.5 db	-0.5 db	Spec LSP-380-17
Pointing	-7.5 db	-7.5 db	-7.5 db	Θ = 65 degrees look angle
Total Losses	-174.0 db	-176.5 db	-176.5 db	
Noise Temperature:				
$T_{receiver}$	435° K	170° K	140° K	From 290° K (F-1)
T_{sky}	30° K	20 K	20° K	
$T_{antenna}$	40° K	40° K	40° K	Back lobes
T_{feed}	40° K	40° K	40° K	
System Temperature	545° K	270° K	240° K	
Noise Density	-111.3 dbm/Mc	-114.3 dbm/Mc	-114.8 dbm/Mc	
Bandwidth	+13.0 db	+7.0 db	+9.3 db	I-F bandwidth
Noise Power, N	-98.3 dbm	-107.3 dbm	-105.5 dbm	
Threshold, C/N	12.0 db	12.0 db	7.0 db	
Effective Power:				
Power	43.0 dbm	43.0 dbm	43.0 dbm	20 watts
Gain, Spacecraft	7.0 db	7.0 db	7.0 db	
Gain, Ground	36.0 db	44.0 db	44.0 db	
Total	86.0 dbm	94.0 dbm	94.0 dbm	
Power Received, C	-88.0 dbm	-82.5 dbm	-82.5 dbm	
$\frac{\text{Power Received}}{\text{Noise Power}} = \frac{C}{N}$	10.3 db	24.8 db	23.0 db	Carrier-to-noise, ψ = 5 degrees
	12.0 db	26.5 db	24.7 db	Carrier-to-noise, ψ = 10 degrees

Abbreviations: F = Frequency
BW = Bandwidth
NF = Noise Figure

must be less than i-f bandwidth with frequency instabilities and Doppler shift deducted. Thus, F_m and F_d determine the output of each receiver. These parameters are tabulated in Table 7 for the line sequential color scheme.

One point must be noted at this juncture. The $(S/N)_{FM}$ out of the receiver will be less than the $(S/N)_V$ out of the camera electronics or video processor. The tabulated figures consider only the equivalent thermal noise (white noise) at the receiver input. Degradation of output $(S/N)_{FM}$ by the noise generated in the video processor need be considered only when the $(S/N)_V$ out of the camera is comparable to the value calculated by equation 2 (Paragraph B36). For the purpose of comparing links, the high values of $(S/N)_{FM}$ in Table 7 are not corrected.

(3) Line Sequential Color System, North American Receiver

The i-f bandwidth of the North American receiver is 20 Mc. Since, the Doppler bandwidth is 80 kc at 1710 Mc and transmitter stability requires 220 Kc, the bandwidth remaining for formation is 19.7 Mc. The desirable value of $\frac{\text{pk-pk video}}{\text{rms noise}}$ is 40 db. With sine-wave burst synchronization, the value

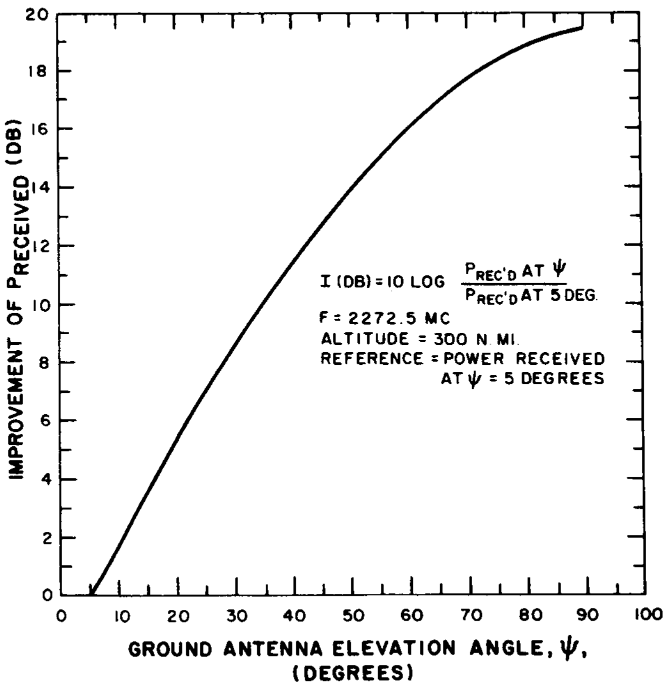


Figure 23. Improvement of Received Power versus Antenna Elevation

TABLE 7. NEAR-EARTH PARAMETERS, LINE SEQUENTIAL COLOR SCHEME

N. American Receiver, BW = 20 Mc								
Parameter	Modulation Bandwidth (Mc)							
	0.5	0.5	1.25	1.25	2.4	2.8	3.8	6.0
Peak Deviation (Mc)	1.0	6.0	2.5	6.0	6.0	6.0	6.0	3.9
R-F Bandwidth (Mc)	3.3	13.3	7.8	14.9	16.8	17.6	20.	20
C/N (db at ψ = 10 deg)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
R-F Margin (db)	0	0	0	0	0	0	0	0
S/N (rms/rms) (db)	35.8	51.4	31.8	39.4	31.0	28.9	25.0	15.2
Worldwide Receiver, BW = 5 Mc								
	0.5	0.5	1.20	1.25	1.25	2.4		
Peak Deviation (Mc)	1.0	1.78	1.44	1.04	1.14	1.14		
R-F Bandwidth (Mc)	3.3	5.0	5.0	5.0	5.0	5.0		
C/N (db at ψ = 5 deg)	24.8	24.8	24.8	24.8	24.8	24.8		
R-F Margin (db)	12.8	12.8	12.8	12.8	12.8	12.8		
S/N (rms/rms) (db)	42.6	50.6	34.4	31.0	31.8	23.8		
MSFN Receiver, BW = 8.5 Mc								
	0.5	1.25	1.25	1.25	2.0	2.8	4.0	
Peak Deviation (Mc)	3.0	2.8	1.14	0.93	2.4	1.9	1.9	
R-F Bandwidth (Mc)	8.3	8.3	5.0	4.0	8.3	8.3	8.3	
C/N (db at ψ = 5 deg)	23.0	23.0	23.0	23.0	23.0	23.0	23.0	
R-F Margin (db)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	
S/N (rms/rms) (db)	47.9	40.5	32.3	30.5	32.7	26.2	21.5	

of $\frac{\text{rms signal}}{\text{rms noise}}$ must be 31 db. This latter requirement is satisfied when $\frac{F_d^2}{F_m^3}$ is greater than or equal to 2.63. A transmitter such as Conic CTM-UHF4 has a peak deviation of 6 Mc. The highest modulation bandwidth (F_m) for this deviation (which satisfied S/N) is 2.4 Mc. The information bandwidth is satisfied when the value of F_m is less than 3.8 Mc, so it is apparent that the signal-to-noise requirement limits the highest value for F_m unless preemphasis is employed. The maximum video baseband which can be transmitted via the North American receiver is 3.8 Mc.

For the recommended baseband of 1.25 Mc, the desirable S/N of 31 db is achieved when F_d is at least 2.5 Mc, and r-f power is 20 watts. A tradeoff is usually possible between transmitter power and deviation ratio (δ). Power may be reduced, if δ is increased so that S/N is kept constant for the link. However, such a tradeoff is not possible for the North American receiver because the received power would drop below the receiver threshold. In other words, there is insufficient r-f margin to afford a power reduction.

(4) Line Sequential Color System, World-Wide Receiver

The parameters for the Worldwide 5-Mc bandwidth receiver are also listed in Table 7. An improvement of 14.5 db in r-f margin is realized over the 1710-Mc link, due to the larger ground antenna and narrower receiver. The narrower i-f constrains F_d and F_m. For significant sidebands 20 db below the unmodulated carrier, F_m and F_d are related as follows in order to satisfy the bandwidth constraint.

F_m Range (Mc)	F_d Max. (Mc)
0.48 - 0.60	1.78
0.60 - 0.80	1.68
0.80 - 1.20	1.44
1.2 - 2.4	1.14

The $\frac{\text{rms signal}}{\text{rms noise}}$ of 31 db is satisfied when F_d^2/F_m^3 is greater than or equal to 0.55 (for the Worldwide receiver). When F_m is 1.25 Mc, a minimum F_d of 1.04 Mc is required to satisfy S/N, and a maximum F_d of 1.14 Mc will satisfy bandwidth.

A transmitter power reduction is afforded with this receiver. At most it is 0.8 db, or a transmitter power of 16.7 watts. Because of the 14.5-db greater r-f margin available in the 2272.5-Mc link, the Worldwide receiver is preferable to the North American unit.

(5) Line Sequential Color System, MSFN Receiver

Although its use in near-earth missions was not explicitly stated in the Statement of Work, the performance of the MSFN receiver is included in Table 7. The $\frac{\text{rms signal}}{\text{rms noise}}$ of 31 db is satisfied when F_d^2/F_m^3 is greater than or equal to 0.49 for this receiver. F_m and F_d are related as follows to satisfy an 8.5-Mc bandwidth constraint:

F_m Range (Mc)	F_d Max (Mc)
0.8 - 1.0	3.0
1.0 - 1.3	2.8
1.3 - 2.0	2.4
2.0 - 4.0	1.9

This receiver can be used for higher video basebands than the Worldwide unit and will provide better r-f margins and S/N. However, because of its complexity, the MSFN receiver may not be desirable for near-earth color television reception. In this case, the Worldwide receiver is recommended, since it provides adequate margin and S/N for a 1.25-Mc video baseband. If MSFN is used, transmitter power may be reduced to 3 watts, resulting in a margin of 7.8 db and a S/N equal to 32.3 db.

(6) Pseudo-NTSC Color System

Prior to selection of the line sequential scheme as the preferred transmission system, calculations had been made for the pseudo-NTSC scheme. The results are tabulated in Table 8 for reference or comparison.

TABLE 8. NEAR-EARTH PARAMETERS: PSEUDO-NTSC SYSTEM

N. American Receiver (BW = 20 Mc)						
Parameter	Modulation Bandwidth (Mc)					
	0.5	0.5	1.25	1.25	4.5	6.0
Peak Deviation (Mc)	1.0	6.0	2.5	6.0	6.0	6.0
R-F Bandwidth (Mc)	1.8	5.0	4.5	8.4	15.2	12.3
C/N (db at ψ = 10 deg)	12.0	12.0	12.0	12.0	12.0	12.0
R-F Margin (db)	0	0	0	0	0	0
S/N (rms/rms) for G (db)	30.5	46.0	26.5	34.2	17.4	13.7
Worldwide Receiver (BW = 5 Mc)						
	0.5	1.25				
Peak Deviation (Mc)	6.0	2.5				
R-F Bandwidth (Mc)	5.0	4.5				
C/N (db at ψ = 5 deg)	24.8	24.8				
R-F Margin (db)	12.8	12.8				
S/N (rms/rms) for G (db)	52.4	33.2				

b. APOLLO

Link parameters are tabulated in Table 9 for Apollo near-earth missions which utilize the USB modulator. Circuit losses in the Apollo equipment are considerably higher than the losses in a separate system. The assumed circuit losses from the transmitter output through the antenna are 5.5 db*. In the color television mode, the r-f power must be switched to the near-earth antenna. Desirable S/N is achieved from the USB transmitter when the ground antenna elevation exceeds 15 degrees.

TABLE 9. NEAR-EARTH LINK PARAMETERS, APOLLO
(Conditions: The Same as Table 6)

Parameter	N. American Receiver	Worldwide Receiver	MSFN Receiver	Comments
Losses				
Line, Spacecraft	-5.5 db	-5.5 db	-5.5 db	Transmitter output through antenna
Total Losses	-178.5 db	-181.0	-181.0	Other losses as in Table 6, θ = 65 degrees
System Temperature	545°K	270°K	240°K	Table 6, unchanged
Noise Power	-98.3 dbm	-107.3 dbm	-105.5 dbm	MSFN, BW = 8.5 Mc
Effective Power	86.0 dbm	94.0 dbm	94.0 dbm	
Power Received	-92.5 dbm	-87.0 dbm	-87.0 dbm	
$\frac{\text{Power Received}}{\text{Noise Power}} = \frac{C}{N}$	+5.8 db	+20.3 db	+18.5 db	C/N at ψ = 5 degrees
R-f Margin	——	8.3 db	11.5 db	ψ = 5 degrees
S/N (rms/rms)	——	27.3 db	36.0 db	F_m = 1.25 Mc, F_d max ψ = 5 degrees
S/N $\frac{\text{rms}}{\text{rms}}$	——	31.0 db	39.7 db	ψ = 15 degrees

* W. Kuykendall, NASA/MSC "LEM Unified S-Band System" Proc. of Apollo USB Technical Conference, GSFC, July 14-15, 1965

6. Far-Earth Link Analysis

a. RECEIVED POWER

The far-earth link parameters from the Apollo and LEM spacecraft to MSFN are listed in Table 10. The LEM video transmission mode for monochrome television presently plans to use a 10-foot erectable dish which will be operative only from the lunar surface, and not during the ascent or descent phases. The gain of the LEM 2-foot steerable antenna is too small, and LEM circuit losses are too great to establish a video link during ascent or descent modes. It is not practicable to include a larger antenna solely for in-flight video on LEM because of weight and stabilization complexity. Therefore, for color video transmission, the link considered for LEM is lunar surface to MSFN. Apollo in a lunar orbit has adequate antenna gain and lower circuit losses so that video transmission to earth is achievable.

The value of worst-case noise temperature with the MSFN antenna centered on the moon is 460°K as listed in Table 10. At perigee, the moon subtends 0.56 degrees; maximum beamwidth of the 85-foot antenna is 0.40 degrees. The S-band moon temperature is 230°K, so that the temperature contribution of the main antenna beam is $0.71 \times 230°K$, or 164°K. Main beam power is 85 percent of the total antenna radiation; therefore, the contribution of the moon to system temperature is $0.85 \times 164°K$, or 140°K. A value of 120°K has been published by Jet Propulsion Laboratories for an 85-foot antenna at 2388 Mc. System temperature with a quiet sky is $270° \pm 50°K$, including antenna, feed, line losses, diplexer, switches, preamplifiers, and the MSFN receiver. Power received from Apollo in lunar orbit is 2.4 db less than power from LEM on the lunar surface. Succeeding comments on the Apollo-earth link apply to LEM-earth with 2.4-db improvement. Apollo r-f margin is 3.4 db for the MSFN receiver with 4-Mc bandwidth.

b. BANDWIDTH AND DEVIATION, MSFN RECEIVER

As mentioned earlier, it is assumed that the r-f spectrum for far-earth links must be less than 5 Mc. Stability of the USB modulator is ± 0.0015 percent, or ± 35 kc. The Doppler bandwidth is 30 kc; therefore, the information bandwidth must be no greater than 4.9 Mc because of r-f channel considerations. The concern at this juncture is whether the video transmission can be achieved using the 4-Mc MSFN bandwidth. The deviation, bandwidth, and margin parameters for the MSFN receiver and the Worldwide receiver are listed in Table 11.

TABLE 10. FAR-EARTH LINK PARAMETERS, APOLLO AND LEM

Conditions: Apollo in lunar orbit
LEM on lunar surface
85-Foot MSFN Antenna
USB Modulator ($F_d = \pm 3$ Mc)
T_{system} at MSFN $= 270 \pm 50°$K (quiet sky)

	Apollo	LEM
Antenna gain	28 db	34 db
Beamwidth	6.5 deg	3 deg
Circuit losses	5.5 db	9.1 db

Parameter	Apollo	LEM	Comments
Losses			
Path	-211.3 db	-211.3 db	At F = 2.272 Gc
Polarization	-0.3 db	-0.3 db	
Atmospheric	-0.5 db	-0.5 db	
Line, Spacecraft	-5.5 db	-9.1 db	LEM includes 65-ft cable
Line, Ground	-0.5 db	-0.5 db	
Pointing	-0.5 db	-0.5 db	Apollo figure assumed for LEM
Total Losses	-218.6 db	-222.2 db	
Noise Temperature, T			
T_{system} quiet sky	320°K	320°K	W. Kuykendall "LEM USB Sys."
T_{moon}	140°K	140°K	
T_{system}, worst case	460°K	460°K	
Noise density	-112.0 dbm/Mc	-112.0 dbm/Mc	
4-Mc bandwidth	6.0 db	6.0 db	
8.5-Mc bandwidth	9.3 db	9.3 db	
Noise Power, N	-106.0 dbm	-106.0 dbm	Bw = 4 Mc
	-102.7 dbm	-102.7 dbm	Bw = 8.5 Mc
Threshold C/N	7.0 db	7.0 db	
Effective Power			
Power	43 dbm	43 dbm	20 watts
Gain, Spacecraft	28 db	34 db	
Gain, MSFN	52 db	52 db	minimum gain
Total	123 dbm	129 dbm	
Power Received, C	-95.6 dbm	-93.2 dbm	
$\frac{\text{Power rec'd}}{\text{Noise Power}} = \frac{C}{N}$	10.4 db	12.8 db	Bw = 4 Mc
	7.1 db	9.5 db	Bw = 8.5 Mc

TABLE 11. FAR-EARTH PARAMETERS, APOLLO

Conditions: Line Sequential Transmission
F_m = 1.25 Mc
Threshold = 7.0 db for MSFN
Threshold = 12.0 db for Worldwide Receiver

MSFN Receiver, Apollo to Earth

Parameter	Modulation Bandwidth (Mc)						
	0.8	0.9	1.0	1.25	1.25	1.25	1.25
Peak Deviation (Mc)	1.2	1.6	1.0	0.93	1.14	2.4	3.0
R-F Bandwidth (Mc)	4.0	5.0	4.0	4.0	5.0	7.5	8.5
Receiver B_{if} (Mc)	4.0	8.5	4.0	4.0	8.5	8.5	8.5
C/N (db)	10.4	7.1	10.4	10.4	7.1	7.1	7.1
R-F Margin (db)	3.4	0.1	3.4	3.4	0.1	0.1	0.1
S/N (rms/rms) (db)	23.0	23.0	21.2	14.6	16.4	23.0	24.8
Acceptable S/N (db) (sinewave sync)	23.0	23.0	23.0	23.0	23.0	23.0	23.0

Worldwide Receiver, Apollo to Earth

Parameter	I-F Bandwidth = 5 Mc
Noise Density	-112.0 dbm/Mc
5 Mc Bandwidth	7.0 db
Noise Power, N	-105.0 dbm
Threshold, C/N	12.0 db
Effective Power	123.0 db
Total losses	-218.6 db
Power received, C	-95.6 dbm
$\frac{\text{Power rec'd}}{\text{Noise power}} = \frac{C}{N}$	9.4 db
Modulation, F_m	1.25 Mc
Peak Deviation	1.14 Mc
R-F Bandwidth	5.0 Mc
R-F Margin	-2.6 db
S/N (rms/rms)	(16.4 db) (This is for reference only. The S/N equation is not valid below threshold.)

Assuming the use of sine-wave burst synchronization, an acceptable rms signal-to-rms noise ratio is 23 db. This value is satisfied when F_d^2/F_m^3 is greater than or equal to 3.0 for the MSFN receiver. As tabulated for a video baseband of 1.25 Mc and line sequential color, F_d must be 2.4 Mc to provide adequate S/N; with this value, however, the r-f bandwidth constraint is exceeded. To meet a receiver bandwidth of 4 Mc, F_d is 0.93 Mc and S/N degrades to 14.6 db. When the wider MSFN bandwidth of 8.5 Mc is considered, F_d must be 1.14 Mc, which results in a S/N of 16.4 db. A comparison of the parameter is more apparent in Table 12, which lists the Apollo-MSFN link parameters with and without the r-f bandwidth constraint.

TABLE 12. APOLLO-MSFN LINK PARAMETERS

Parameter	R-F Bandwidth Unconstrained F_m = 1.25 Mc		R-F Bandwidth = 5 Mc F_m = 1.25 Mc	
	B_{IF} = 4 Mc	B_{IF} = 8.5 Mc	B_{IF} = 4 Mc	B_{IF} = 8.5 Mc
Peak Deviation (Mc)	0.93	3.0	0.93	1.14
R-F Bandwidth (Mc)	4.0	8.5	4.0	5.0
C/N (db)	10.4	7.1	10.4	7.1
R-F Margin (db)	3.4	0.1	3.4	0.1
S/N, $\frac{\text{rms signal}}{\text{rms noise}}$ (db)	14.6	24.8	14.6	16.4

The link S/N is degraded by 8.4 db due to the r-f bandwidth constraint. It is apparent that the 8.5-Mc bandwidth is better in terms of S/N; however, the 4-Mc bandwidth affords 3.3 db more margin above threshold. In order to produce adequate S/N in a 4-Mc bandwidth, the value of F_m would have to be 0.8 Mc. As will be shown later, S/N can be improved substantially by preemphasizing the video signal prior to modulation of the transmitter. The r-f margin is, therefore, the main concern for the link.

c. BANDWIDTH AND DEVIATION, WORLDWIDE RECEIVER

The far-earth link parameters for a system using the Worldwide unit are listed in Table 11. This receiver cannot be utilized for a 1.25-Mc baseband because carrier level is below threshold. Modification of the demodulator to a phase-lock loop (PLL) could improve threshold C/N by at least 3 db. The r-f margin would then be 0.4 db and S/N would be 16.4 db. With a lower threshold, the S/N performance of the Worldwide receiver becomes comparable to the 8.5-Mc bandwidth MSFN receiver and has at least 0.3 db greater r-f margin. (Again, this value of margin applies under the r-f spectrum constraint.)

d. ALTERNATIVES

Various system alternatives for improving margin and S/N to an acceptable value are listed in Table 13. The Deep Space Instrumentation Facility (DSIF) presently utilizes a maser preamplifier with a noise temperature for the system (quiet sky) of 55 ± 10°K (per JPL TM33-83). The use of a similar unit would enhance r-f margin by 3.5 db. As mentioned earlier, the use of a larger spacecraft antenna is not considered due to the added weight and complexity. A separate antenna would required switching of r-f power from the USB transmitter and would thus reduce reliability of other Apollo modes.

In order to minimize modifications to existing equipment, the use of a separate modulator-transmitter is not recommended for the primary far-earth missions. A separate transmitter should be considered, however, for color television inclusion in the Pallet experiments. Alternatives I, J, and K (Table 13) list the choices for the Pallet and the extended missions in which weight and volume are not constraints. With a separate r-f system, circuit losses are reduced by as much as 4.0 db. The resulting margin and S/N for 20 watts of power at the output of the power amplifier are shown in Table 13.

In the pseudo-NTSC system, the modulator has a deviation which must be shared by the red, green, and blue signals. The line-sequential system affords the possibility of enhancing S/N, because each color baseband can deviate the transmitter fully. This S/N advantage would not be realized in the line sequential system if F_m, the modulation baseband, were increased. It is also not realized when an r-f spectrum constraint is assumed, since S/N improvement is achieved at the expense of bandwidth. Alternatives L, M, and N (Table 13) indicate the S/N improvement available without an r-f bandwidth limitation.

7. Apollo Applications

a. EXTENDED CAPABILITIES

The basic Apollo missions can be extended to missions not involving a LEM capsule. Such extensions, as well as the Apollo Pallet (refer to Section IIIE), will allow additional weight, volume, and power capability. Additional power permits the consideration of a separate transmitter and greater

TABLE 13. FAR-EARTH ALTERNATIVES, APOLLO

Conditions: Same as in Table 11
Max. R-F Bandwidth = 5 Mc, except where noted
F_m = 1.25 Mc
LEM performance is 2.4 db better

Alternative	Transmitter	$\pm F_d$ (Mc)	Receiver	B_{IF} (Mc)	Preamplifier	Other	Margin (db)	S/N, db $\left(\frac{rms}{rms}\right)$	Comments
A	Apollo-USB	0.93	MSFN	4.0	Paramp		3.4	14.6	
B	Apollo-USB	0.93	MSFN	4.0	Maser		6.9	18.1	T system = 65° K per JPL TM 33 - 83
C	Apollo-USB	1.14	MSFN	8.5	Paramp		0.1	16.4	
D	Apollo-USB	1.14	MSFN	8.5	Maser		3.6	19.9	T system = 65° K
E	Apollo-USB	1.14	Worldwide	5.0	Paramp		-2.6	(16.4)	Below 12 db Threshold
F	Apollo-USB	1.14	Worldwide	5.0	Paramp	PLL	0.4	16.4	C/N = 9 db at Threshold
G	Apollo-USB	1.14	Worldwide	5.0	Maser		0.9	19.9	T system = 65° K
H	Apollo-USB	1.14	Worldwide	5.0	Maser	PLL	3.9	19.9	C/N = 9 db at Threshold
I	New	1.14	Worldwide	5.0	Paramp		1.4	20.4	Spacecraft Circuit Losses = 1.5 db
J	New	0.93	MSFN	4.0	Paramp		7.4	18.6	Spacecraft Circuit Losses = 1.5 db
K	New	1.14	MSFN	8.5	Paramp		4.1	20.4	Spacecraft Circuit Losses = 1.5 db
L	Apollo-USB	3.0	MSFN	8.5	Paramp	$B_{RF} \neq 5$ Mc	0.1	24.8	R-F Unconstrained
M	Apollo-USB	3.0	MSFN	8.5	Maser	$B_{RF} \neq 5$ Mc	3.6	28.5	R-F Unconstrained
N	New	3.0	MSFN	8.5	Paramp	$B_{RF} \neq 5$ Mc	7.4	28.8	R-F Unconstrained

Abbreviation: Paramp = Parametric Amplifier video bandwidth with reception via a wideband receiver such as the North American unit. The transmitter characteristics listed below are considered within the state-of-the-art development by 1970:

Peak deviation, F_d	± 10 Mc
Baseband, F_m	8 Mc
R-f power	50 watts

The communication system capability for a near-earth, 300-nautical-mile orbit using the North American receiver is tabulated in Table 14.

TABLE 14. SYSTEM PARAMETERS, APOLLO PALLET

Parameter	Value	Comments
Losses, L	-174 db	Refer to Table 6
Noise Temperature, sys.	545°K	Parametric Amplifer
Noise Density	-111.3 dbm/Mc	
Bandwidth, B_{IF}	+13.0 db	20 Mc I-F Bandwidth
Noise Power, N	-98.3 dbm	
Threshold, C/N	12.0 db	
Effective Power		
Power	47 dbm	50 watts
Antenna, Spacecraft	7.0 db	Refer to Figure 10
Antenna, Ground	36.0 db	16 ft.
Total	90 dbm	
Power Reveived, C	-84 dbm	
C/N	14.3 db	
R-F Margin, M	2.3 db	at $\psi = 5$ degrees

To achieve a desirable S/N ratio with the North American receiver, F_d^2/F_m^3 must be greater than 1.55. By Carson's Rule,

$$2(F_m + F_d) = B_{IF}.$$

Substituting to satisfy both S/N and bandwidth conditions,

$$\frac{B_{IF}}{2} = F_m + (1.55\ F_m^3)^{\frac{1}{2}}.$$

Thus, the maximum F_m becomes 3 Mc, for which F_d is 6.5 Mc. The link has a minimum margin of 2.3 db and is operable with an antenna elevation as low as 5 degrees. Desirable S/N of 31 db is achieved at this elevation even with a 16-foot antenna because of the high deviation capability of the transmitter.

The transmission of wider video basebands requires a receiver with a wider bandwidth. For example, when F_m is equal to 4 Mc and F_d is equal to 10 Mc, the receiver bandwidth should be 30 Mc. The resulting C/N is reduced to 12.5 db for a 16-foot antenna. The desirable S/N is obtained when F_d^2/F_m^3 is greater than or equal to 1.57. This value is satisfied by the assumed baseband and deviation. The extended missions will, therefore, allow consideration of wider bandwidths with minimum change to the ground equipment. When F_m is greater than 1.5 Mc, a separate system must be employed because the USB modulator capability will be exceeded.

b. APOLLO PALLET SYSTEM, NATURAL RESOURCES CAMERA

Color schemes in addition to the 1.25-Mc variable-line sequential and pseudo-NTSC systems have been considered in Section III E, Apollo Applications. In that section, schemes defined as Equal-Line Sequential or Equal-Resolution Frame Sequential are shown to require basebands of 2.8 Mc and 16.5 Mc. Because of its 5 Mc i-f bandwidth, the Worldwide receiver cannot be employed at all. The MSFN and the North American receivers can be considered for the 2.8-Mc baseband, and tabulations listed in Table 7 are applicable. The preferred receiver is MSFN because of its higher r-f margin. For the 16.5-Mc baseband, no S-band transmitter or receiver is available.

Simultaneous readout schemes which transmit three color basebands on three subcarriers are also discussed in Section III E. When modulated, each subcarrier channel will have a bandwidth of 1.9 Mc or 11 Mc for double sideband (DSB-AM). Present modulator capability disallows the latter bandwidth. The scheme with 1.9-Mc subcarriers bandwidths will have a premodulation spectrum shown in Figure 24. Output S/N in the ratio of 59:30:11 for green, red, and blue, respectively is achieved by apportioning the transmitter deviation as follows:

Color	$\pm F_d$ (Mc)	Peak F_m (Mc)	B_{RF} (Mc)
Green	1.3	1.9	6.4
Red	2.4	3.8	12.4
Blue	2.3	5.9	16.0
	6.0		

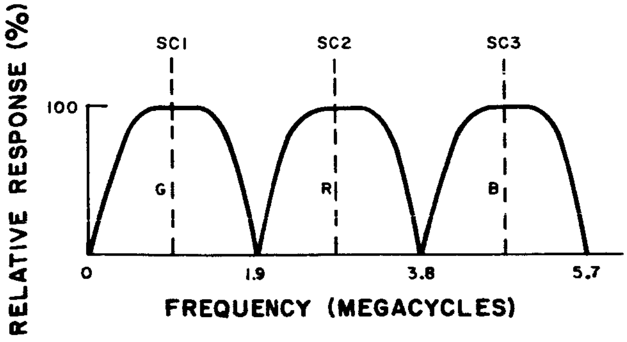


Figure 24. Premodulation Spectrum for System Using Three Color Subcarriers

Neither the MSFN nor the Worldwide receivers can be employed because of the r-f bandwidth requirements indicated above. The $\frac{\text{rms signal}}{\text{rms noise}}$ calculated for the green channel is 28 db with the North American receiver, a 30-foot antenna, and a 20-watt transmitter.

8. Recommended Systems

a. NEAR-EARTH

The preferred components for near-earth missions are indicated in Table 15 and Figures 25 and 26. This choice is qualified, since Apollo power amplifiers can operate in a 5-watt mode as well as in the 20-watt mode. If MSFN receivers are available, lower transmitter power can be used as shown in Table 16.

b. FAR-EARTH

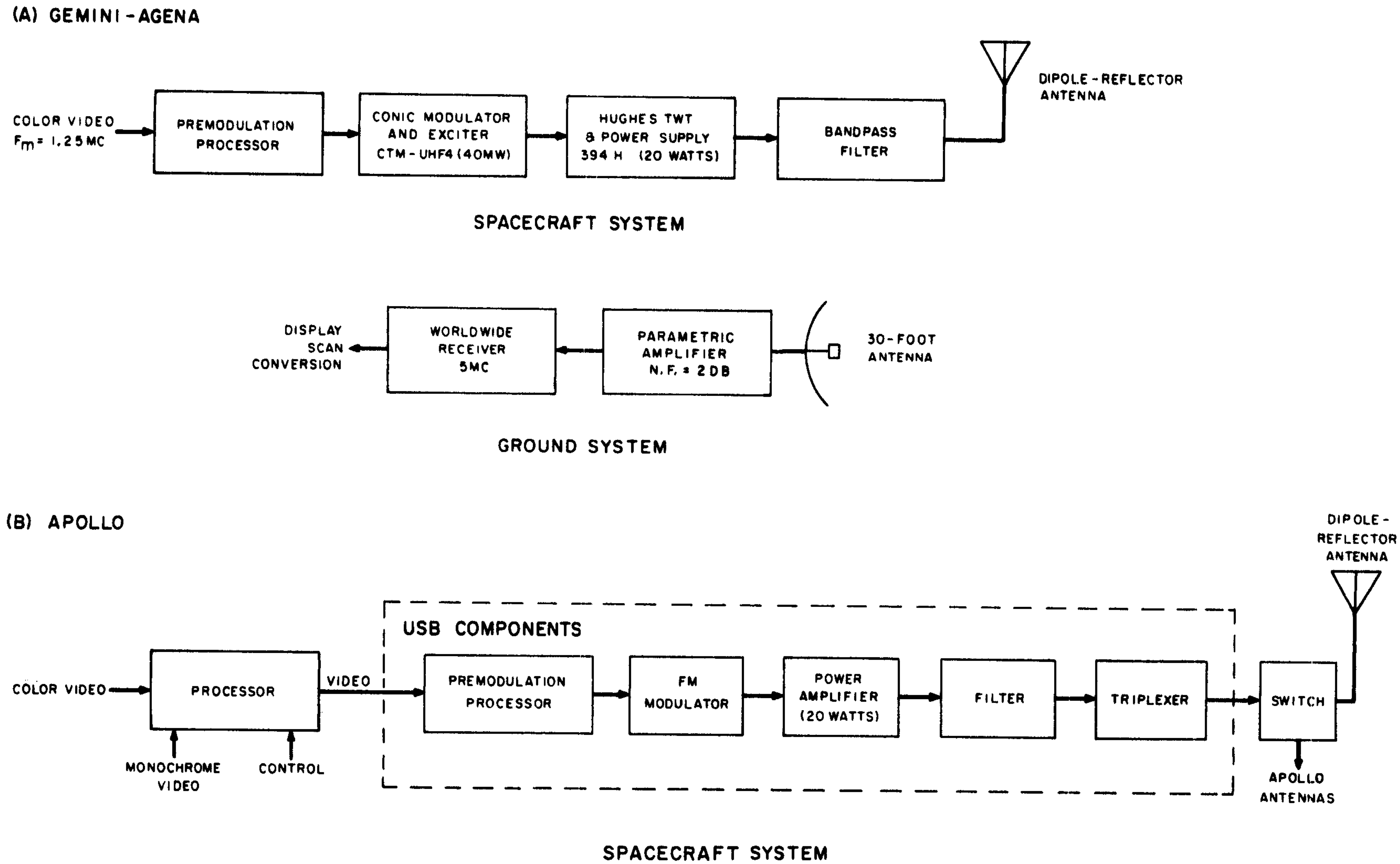
The recommendations for the far-earth missions are that the 5-Mc constraint on the r-f spectrum should not be applied to color television transmission. This will allow the full use of the performance capability of the r-f equipment. Under this condition, the recommended system is the MSFN receiver with an 8.5-Mc i-f bandwidth and a maser preamplifier. In this configuration (Alternative M, Table 13), the r-f margin and S/N are adequate. The 8.5-Mc MSFN receiver is also recommended for the condition of constrained bandwidth if a maser preamplifier is used. If a parametric amplifier is used (Alternative A, Table 13), the 4-Mc MSFN receiver is recommended.

TABLE 15. PREFERRED NEAR-EARTH COMPONENTS; IF MSFN RECEIVER IS UNAVAILABLE

Components and Parameters	Gemini-Agena (Power = 20 watts)	Apollo (Power = 20 watts)
Premodulation processor	Developed	USB, modified
Modulator/exciter	CONIC CTM-UHF 4 modified	USB
Power amplifier	HUGHES 394 H	USB (also 394 H)
Bandpass filter	MICROLAB BJ-A26	USB
Spacecraft antenna	Dipole-reflector	Dipole-reflector
Ground antenna	30 ft	30 ft
Receiver	Worldwide	Worldwide
R-F margin at $\psi = 5°$	12.8 db	8.3 db
S/N $\left(\frac{\text{rms}}{\text{rms}} \text{ at } \psi = 5°\right)$	31.8 db	27.3 db

TABLE 16. PREFERRED NEAR-EARTH COMPONENTS; IF MSFN RECEIVER IS AVAILABLE

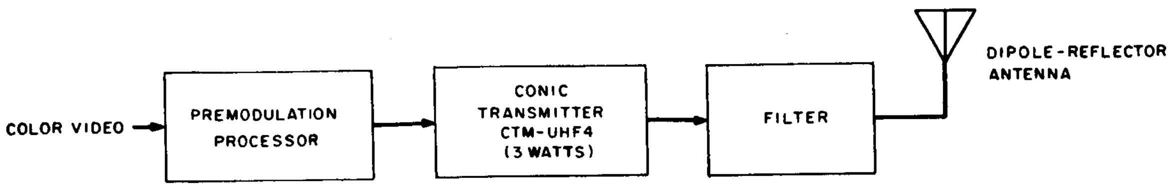
Components and Parameters	Gemini-Agena (Power = 3 watts)	Apollo (Power = 5 watts)
Premodulation processor	Developed	USB, modified
Transmitter	CONIC CTM-UHF 4	USB
Bandpass filter	MICROLAB BJ-A26	USB
Spacecraft antenna	Dipole-reflector	Dipole-reflector
Ground antenna	30 ft	30 ft
Receiver	MSFN	MSFN
R-F Margin at $\psi = 5°$	7.8 db	5.5 db
S/N $\left(\frac{\text{rms}}{\text{rms}} \text{ at } \psi = 5°\right)$	32.3 db	30.0 db



NOTE:
GROUND SYSTEM AS IN GEMINI-AGENA ABOVE.

Figure 25. Near-Earth Recommended Systems (If MSFN Receiver Is Unavailable)

(A) GEMINI - AGENA



SPACECRAFT SYSTEM

NOTE:
GROUND SYSTEM SAME AS IN FIGURE 25(B)

(B) APOLLO

SAME AS SYSTEM SHOWN IN FIGURE 25(B) WITH POWER AMPLIFIERS OPERATING IN 5-WATT MODE. GROUND SYSTEM SAME AS IN FIGURE 20.

Figure 26. Near-Earth Recommended System (If MSFN Receiver Is Available)

When the $\frac{\text{rms signal}}{\text{rms noise}}$ is below the acceptable value of 23 db, as it is for constrained cases, preemphasis must be used to improve S/N performance. The Worldwide receiver is not recommended for far-earth links because of its low r-f margin. The recommended systems are indicated in Figure 27.

The values of S/N and r-f margin are those listed in Table 13. The recommended use of the LEM amplitrons is conditional, and subject to improvement of their reliability, performance, and future qualification.

c. APOLLO APPLICATIONS

Separate r-f systems should be used for the Apollo extended missions and missions utilizing the Pallet configuration. The near-earth r-f system shown in Figure 28 is similar to the Agena system. The power requirement for this system will depend on the particular near-earth orbit and mission profile.

The far-earth r-f system for color television transmission (Figure 27) includes a separate directive antenna, because diplexing of the Apollo and color television signals to the present antenna would introduce additional circuit loss to existing Apollo modes. The separate antenna recommended is a unit such as

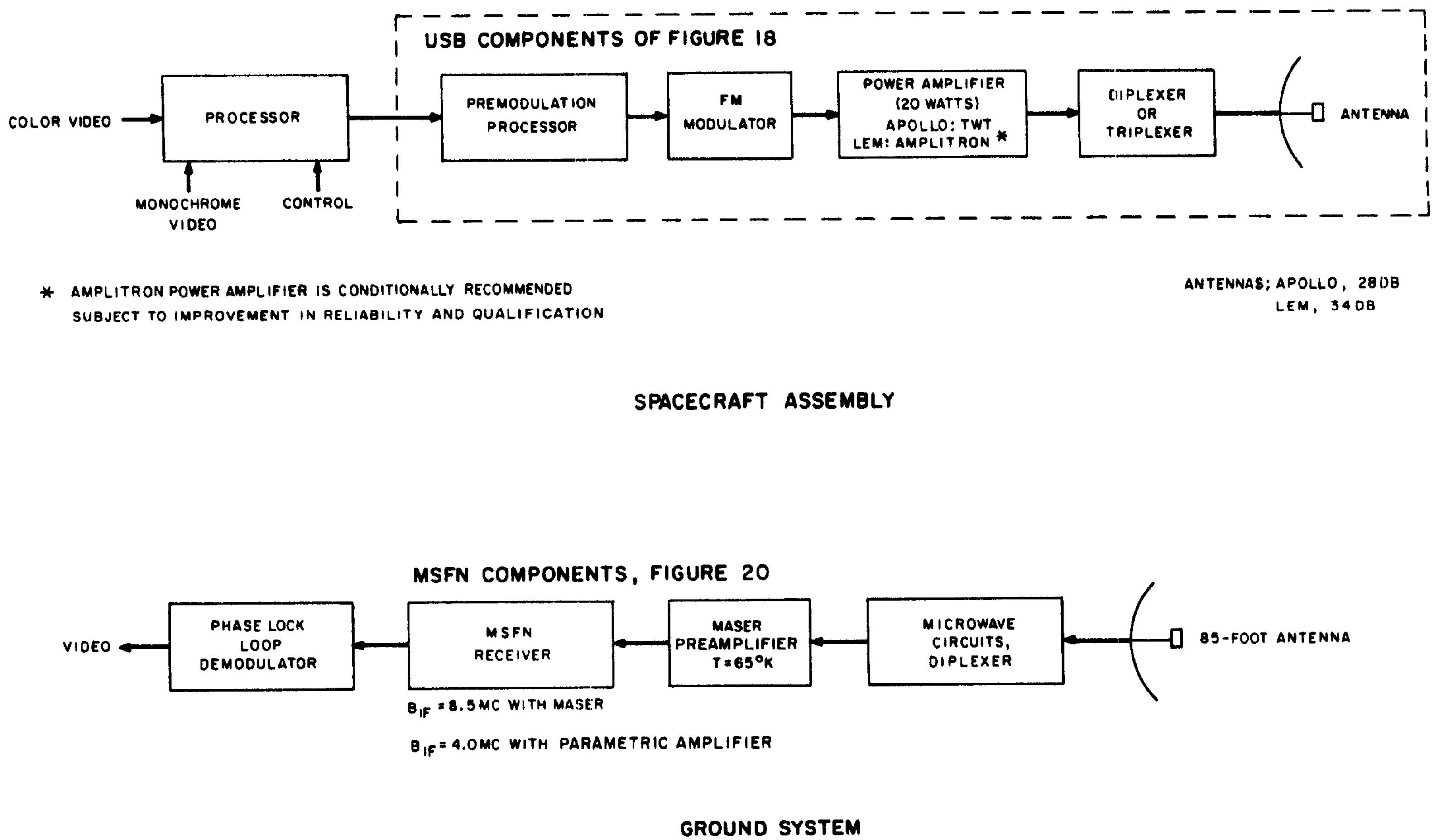


Figure 27. Far-Earth Recommended Systems

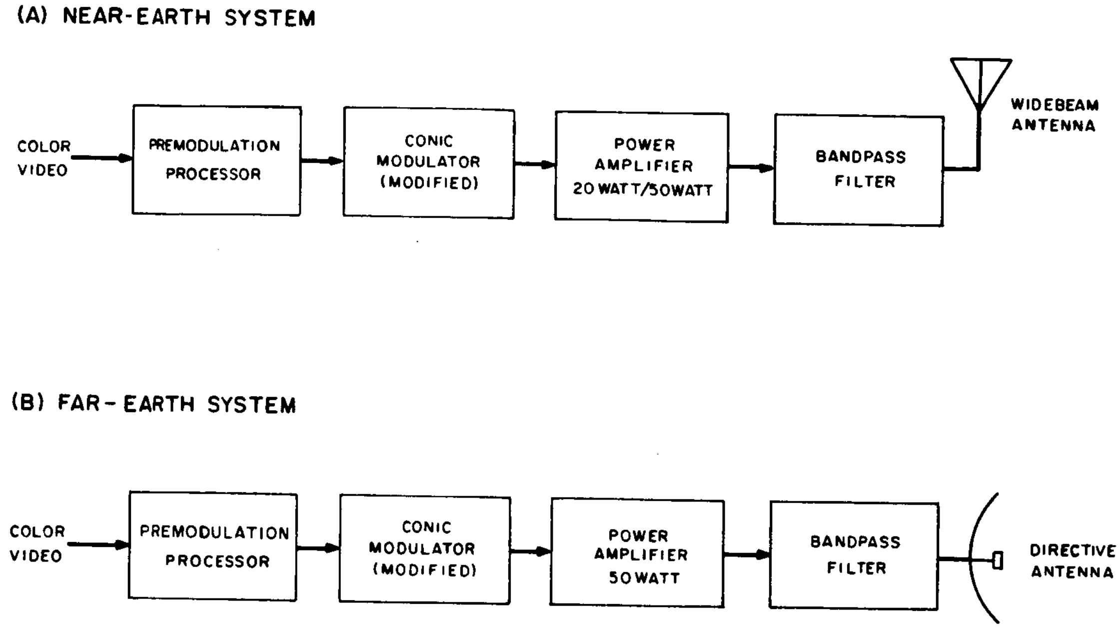


Figure 28. Apollo-Extended and Pallet Recommended System

the existing Apollo antenna or a parabolic dish similar to the Lunar Orbiter antenna. A system other than USB must be used whenever the baseband (F_m) is greater than 1.5 Mc, which is the limit of the USB modulator capability. Circuit losses will be lower than USB so that r-f system performance is enhanced by the separate system.

9. Other Considerations

a. PREEMPHASIS OF VIDEO SIGNALS

The outline of the spectrum of a resolution-chart signal* is shown by curve A-A, Figure 29. This curve is considered the typical video spectrum and is scaled to a 1.25-Mc baseband. The S/N at the output of the receiver can be improved if the high frequency components of the video signal are emphasized prior to transmitter modulation. At the receiver, the high frequency components are deemphasized to restore the original signal-power distribution. The deemphasis also reduces high frequency components of the noise and effectively increases S/N.

* D. Fink, "Television Engineering Handbook," Fig. 10-16, p. 10-18, McGraw-Hill, 1957.

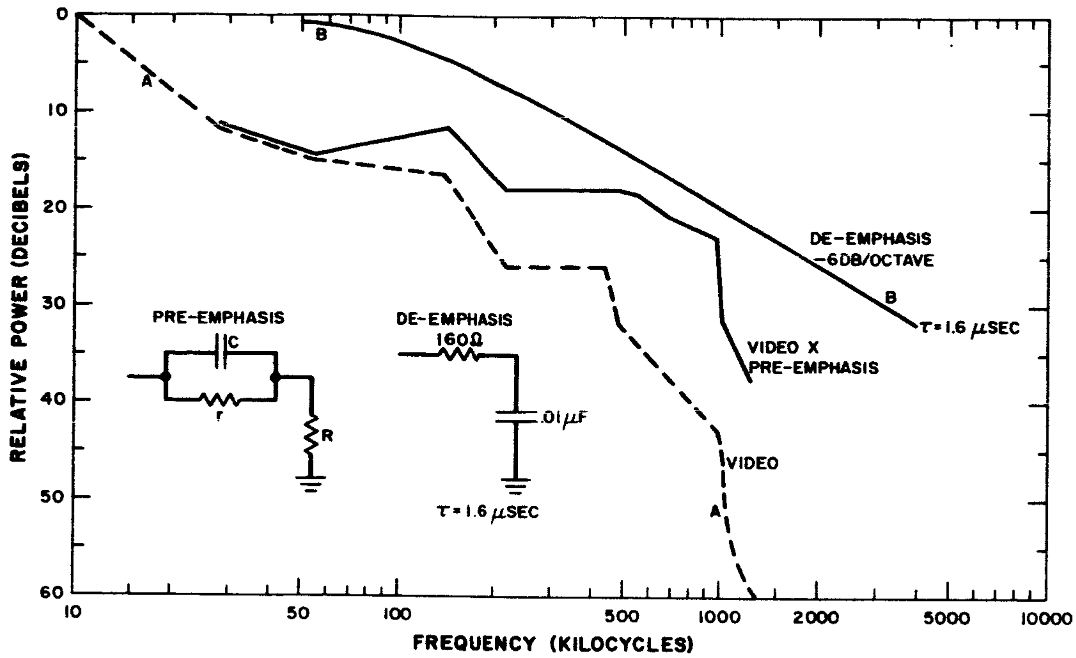


Figure 29. Preemphasis of the Video Baseband

Curve B-B of Figure 29 is a typical deemphasis characteristic available from a simple R-C network. For a time constant of 1.6 microseconds, the frequencies below 0.1 Mc (F_D) are essentially not deemphasized. Above 0.2 Mc, the deemphasis is -6 db per octave. Output noise is decreased by $3\left[\frac{F_D}{F_m}\right]^2$ according to Schwartz*. The S/N improvement is the same as the noise reduction. When F_m has a value of 1.25 Mc and F_D has a value of 0.1 Mc, improvement is about 17 db. In systems where the USB modulator is utilized, a preemphasis network can be designed into the premodulation processor. For systems using the separate transmitter (Conic CTM-UHF4), preemphasis can be designed into the transmitter. The deemphasis network must follow the video demodulator. It is apparent that preemphasis techniques can improve S/N for all links to a level greater than the acceptable requirement.

b. COMMUNICATION SATELLITE LINKS

In far-earth missions, one of the MSFN ground stations will always be able to communicate with Apollo spacecraft, except for the time Apollo orbits around the dark side of the moon. In near-earth missions, the maximum viewing

* M. Schwartz, "Information Transmission, Modulation, and Noise," McGraw-Hill, 1959.

time by one ground station is 14 percent of the orbital period. As shown by the geometry in Figure 30, a relay link via a synchronous communication satellite could conceivably provide each ground station with a viewing time that is as much as 55 percent of the orbital period. Such a relay is considered here. Non-synchronous communication satellites are not considered because the mutual viewing geometry between spacecraft, satellite, and ground station is very complex.

Synchronous communication satellites have been allocated receiving channels in the 6-Gc band, and transmitting channels in the 4-Gc band. The most practical system configuration would be installation of 6-Gc equipment on the spacecraft, including modulator, power amplifier, and antenna. However, qualified 6-Gc hardware suitable for space application is not available at this time. Other considerations show the added complexity of this relay link. In order to maintain communication, the Agena or Apollo spacecraft must have a directive, tracking antenna capable of gimballing over a 230-degree cone. The high antenna directivity will require automatic tracking, which can be accomplished by locking on the 4-Gc transmission of the communication satellite. The sample link analysis in Table 17 shows the magnitude of the r-f problems inherent in this relay.

With the link assumptions indicated in Table 17, the link is deficient by at least 14 db. The receiving antenna gains of planned communication satellites do not exceed 4 db (Apollo Comsat). If the addition of a 17.5-db directive antenna on the communication satellite cannot be accomplished, then the link deficiency is 27.5 db. It is apparent that a communication relay via satellite for a near-earth mission is not practical. Essentially, the difficulty stems from the attempt to install ground station capability (power, tracking, gain) on board the near-earth spacecraft. Consideration of such a relay is, therefore, not recommended.

10. Hardware Specifications

a. MODULATOR-EXCITER

The unit recommended as the exciter for the power amplifier or as the transmitter for low power links is the Conic Model, CTM-UHF4. It is completely solid-state and has been qualified for use in the Saturn 1C. Characteristics for the unit are shown in Table 18.

Circuitry is required to control the color video amplitude and to switch the modulator input from monochrome to color signals. This circuitry could be added to the USB premodulation processor, or it could be a separate signal processor.

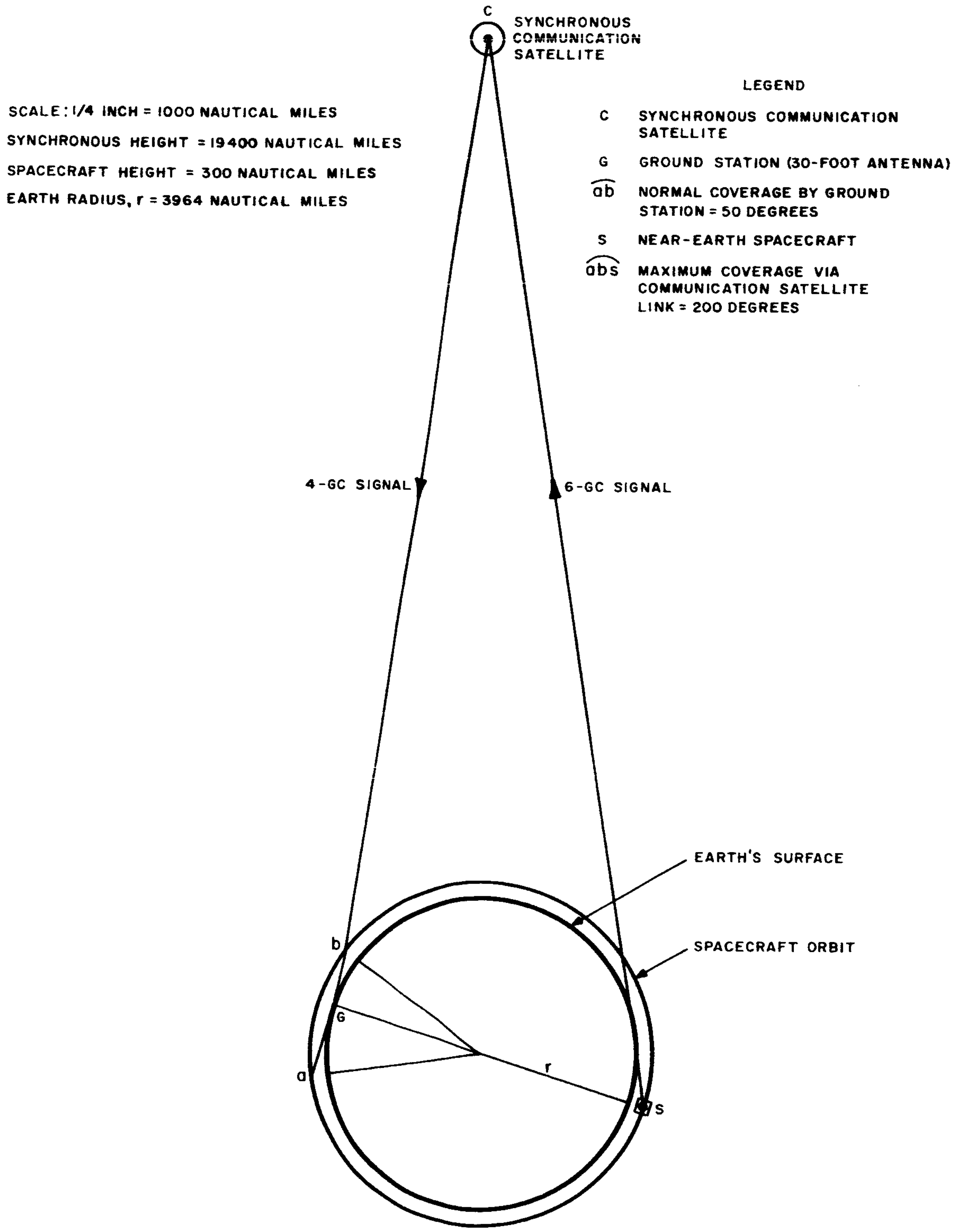


Figure 30. Geometry of Communication Satellite Link

TABLE 17. SAMPLE ANALYSIS OF COMMUNICATION SATELLITE LINK

Parameter	Value	Comments
Losses:		
Path	-201.4 db	Range: 6-Gc path shown in Figure 29
Circuit	-2.0 db	1 db each end
Pointing, Satellite	-3.0 db	Spacecraft off peak of beam
Pointing, Spacecraft	-0.6 db	
Polarization	0 db	Circular to circular
Total Losses, L	-207 db	
Noise Temperature, T	290°K	Communication satellite sees earth; noise figure of receiver is not included in example.
Receiver Bandwidth, B	5 Mc	Assumed value. Communication satellites have various bandwidths ranging from 0.5 Mc to 125 Mc.
Noise Power, N	-107 dbm	A minimum level used only in example. Actual level would be greater.
Transmitter Power	43 dbm	20 watts
Antenna Gain, Spacecraft	32.5 db	3 ft. dish similar to Lunar Orbiter
Antenna Gain, Satellite	17.5 db	Max. receiving gain, 20-degree beamwidth
Power Reveived, C	-114.0 dbm	
Link Deficiency	14 db	For $\frac{C}{N} = 7$ db

TABLE 18. CHARACTERISTICS OF MODULATOR-EXCITER

Manufacturer	Conic Corp., San Diego, California
Model	CTM-UHF4, modified for sine-wave sync and lower output
Frequency	2.2-Gc band
Frequency Stability	± 0.005 percent
Modulation Capability	D-C to 8 Mc
Peak Deviation	± 6 Mc
Output Power, R-F	3 watts, 40 mw (as driver)
Input Power, D-C	49 watts, 13 watts (as driver)
D-C Requirements	28 ± 4 vdc
Size (inches)	5-5/8 × 4-5/8 × 1-5/16; 4-5/8 × 4-5/8 × 1-3/16 (as driver)
Weight (ounces)	32, 26 (as driver)
Temperature	-30° to 80°C (-22° to 176°F)
RFI	Meets MIL-I-26600 for antenna conducted and radiated interference, and for box and power line conducted or radiated interference.
Shock	Each axis, 100 G, 11 milliseconds
Vibration	20 G peak from 20 to 2000 cps

b. POWER AMPLIFIER

The recommended power amplifier for near-earth and Apollo extended applications is the Hughes TWT, model 394H. It is fully qualified for present space programs including Apollo. Characteristics for the unit are shown in Table 19.

TABLE 19. CHARACTERISTICS OF POWER AMPLIFIER

Manufacturer	Hughes Microwave Tube Division Los Angeles, California
Model	394H
Frequency	2.2-Gc band
Output Power, R-F	20 watts
Drive Power, R-F	40 milliwatts
Gain	27 db
Input Power, D-C	84 watts, for the integrated package with TWT and power supply
Efficiency	24 percent
Volume	144 cubic inches, package
Weight	6 lbs, package
Expected Tube Life	25,000 hours
Vibration	30 G, 20 to 2500 cps

c. DIPOLE-REFLECTOR ANTENNA

The recommended dipole-reflector antenna is a developmental device. Its expected characteristics are shown in Table 20.

d. BANDPASS FILTER

The recommended bandpass filter was used on a previous TWT amplifier program. Its characteristics are shown in Table 21.

TABLE 20. CHARACTERISTICS OF DIPOLE-REFLECTOR ANTENNA

Gain, on Axis	7 db above circular isotropic
Polarization	Right-hand circular
Axial Ratio	0.7 db on-axis 2.4 db at -10 db points
Beamwidth	156 degrees at -10 db
Back Radiation	-25 db
VSWR	1.10 max
Weight	12 oz

TABLE 21. CHARACTERISTICS OF BANDPASS FILTER

Manufacturer	Microlab/FXR, Livingston, N.J.
Model	BJ-A26
Center Frequency, F_c	2.25 Gc
Attenuation at F_c	0.5 db max
Attenuation, Harmonics	60 db min
VSWR	1.4 max from (F_c-50 Mc) to (F_c + 50 Mc)
Weight	8 oz

e. SYSTEM WEIGHT AND POWER REQUIREMENTS

The weight and power requirements added to the spacecraft by the recommended near-earth r-f system are listed in Table 22. Totals shown are the maxima for primary missions. Far-earth missions utilizing the USB transmitter will only require the development of a signal processor.

TABLE 22. SYSTEM WEIGHT AND POWER REQUIREMENTS

Component	D-C Power (watts)		Weight (oz.)	
	R-F = 20 watts	R-F = 3 watts	R-F = 20 watts	R-F = 3 watts
Modulator-exciter (plus additional switching and processing circuits	13	49	26 (6)	32
Power Amplifier, TWTA	84		96	
Bandpass Filter			8	8
Spacecraft Antenna			12	12
Cabling Connectors, etc.			16	14
Totals	97 watts	49 watts	164 oz. (10-1/4 lb.)	72 oz. (4-1/2 lb.)

C. CAMERA AND SENSOR STUDY

1. Camera Systems

a. GENERAL

The discussion of various color systems in Section IIA primarily deals with cameras from which three independent video signals are available, either simultaneously or serially. The study has also considered somewhat more unorthodox camera concepts. The use of one image sensor to generate two or more chrominance video signals is very attractive as a possible means of reducing the size, weight, and power requirements for the color camera. Various approaches are discussed.

b. TRI-COLOR VIDICON

Considerable work has been done toward making a tri-color vidicon which has stripe filters for the three primary colors deposited on the inside of the faceplate. The target is also divided into three electrically separate areas to allow simultaneous readout of the red, green, and blue signals as the beam scans the raster. This concept has been reduced to practice*, but the results were quite marginal due to cross talk, dilution of colors and other problems discussed in the referenced paper. Apparently, there has been almost no effort in this area since the lated 1950's.

It is felt that while a tri-color vidicon may still be beyond the state-of-the-art and have fundamental problems, a two-color vidicon used only for the chrominance signal may be realizable with reasonable development effort. The performance requirements for such a vidicon are considerably relaxed due to the reduced resolution and signal-to-noise requirements for the chrominance signal.

---

* P.K. Weimer, S. Grey, C.W. Beadle, H. Borkan, S.A. Ochs and H.C. Tompson, "A Developmental Tri-color Vidicon having a Multiple Electrode Target," Trans I.R.E. July 1960.

c. TRI-COLOR VIDICON WITH AN EXTERNAL FILTER

A somewhat less sophisticated version of the tri-color vidicon can be obtained by putting the stripe filter at the real image point in the optical path and re-imaging the filtered picture on the standard image tube. The disadvantages of this system are:

(1) It is difficult to separate the three color signals out of the continuous video coming from the image tube because of non-linearities in the scanning raster. Some progress has been made in separating the signals by using stripes of different widths or adding a fourth stripe of black to act as an index;

(2) The resolution of the sensor must be roughly three times the resolution required for the luminance signal;

(3) The sensitivity is low because the light from all three spectrums falls on each filter and is absorbed if not passed. Whereas, in the dichroic mirror system for the three-tube cameras, the green light goes to the green tube, the red light to the red tube, etc. This loss is also true of the tri-color vidicon previously discussed.

(4) The optical system required for re-imaging the picture on the sensor is complex and bulky. This difficulty can be alleviated by putting the filter on the outside of the tube face and using fiber optics for the faceplate; however, this method will degrade the resolution somewhat.

d. TRI-COLOR FILTER WITH A SEPARATE LUMINANCE TUBE

The resolution can be improved by using a separate image tube for the high-resolution video channel. NHK in Japan has made such a camera, using two image orthicons. The stripe filter is made up of 72 quads of red, blue, green, and black; the black to aid the decoding problem.

This concept can also be employed using a two-color filter and generating the third color by subtracting the first two color signals from the luminance video coming from the second tube. This method has the disadvantage of complicating the registration problem and colorimetry of the system due to differential gamma, etc.

A line sequential version of this two-tube system is discussed in Section IIA9e of this report.

e. SUMMARY

The several variations of the stripe filter system have proven more attractive in concept than in practice. In applying this concept to the space color application, the registration and bandwidth considerations must be kept in mind.

The single-tube tri-color filter system does not have a registration problem; however, it does require that the sensor have high resolution relative to the required picture resolution. Since the vertical resolution of the picture is equal in all three channels, the system is less efficient from the standpoint of bandwidth conservation than the three-tube variable-line sequential approach. Also, there is the problem of color dilution due to the beam overlapping two filter areas at the same time, and if there is motion, the color fidelity will be degraded by the incomplete erasure of the residual image. This subtle factor will be especially evident at the slow frame rate (7.5 frames per second).

The two-tube tri-color filter system circumvents the problems of bandwidth conservation and a high resolution sensor associated with the single-tube system. The two-tube system still has the color fidelity problem with the added complication of having to match the gamma characteristics of the two tubes and also to register the images. It also has more complicated optical problems.

In conclusion, the disadvantages of the one-tube stripe filter camera outweigh its only real attirbute, one image tube. The two-tube camera gives up part of the advantage in size and eliminates the high resolution filter-sensor problem at the expense of other complications. Thus, as long as the three-tube camera can be built in a reasonable size for hand-held operation, it is the best overall camera system to use for motion picture color television for the space applications.

2. Requirements of Image Sensor

a. GENERAL

Color television imposes tighter requirements on the image sensor than does monochrome operation. Essentially, this results from the requirement for "tracking" of electrical characteristics between the individual image sensors used in the camera. In a typical broadcast color camera using either 3 or 4 sensors, the red, green, and blue signals are generated from three separate sensors. The resulting color presentation on a receiver is the result of proper matrixing of the red, green, blue, and luminance signals. Therefore, for proper color fidelity of each resolution element, the individual red, green, and blue sensors must each be scanning the identical "scene element" at the same time. This requirement imposes strict requirements on deflection linearity, geometrical distortion, raster size and centering, and potential scanning irregularities such as beam bending and profile shift.

Similarly, the sensors must match in electrical characteristics, if the overall system transfer characteristic is to be uniform. These characteristics include gamma, dark current, shading (signal uniformity), etc. If the sensors do not match, their electrical output signals must be modified accordingly by additional circuitry.

The proposed color television system described in this report has been selected to minimize the effect of the preceding requirements on the size and complexity of the space-borne portions of the television system. Transmission of separate red, blue, and green video signals from the spacecraft in conjunction with processing and registration at the ground station considerably reduces the performance requirements which exist for conventional broadcast color cameras. Primarily, the requirements on deflection linearity, geometrical distortion, size and centering, and electrical transfer characteristics can be reduced. However, the tight specification on dynamic deflection non-linearity resulting from beam bending and profile shift must be maintained.

The available image sensors which might conceivably be used in the space camera are:

(1) Vidicons;

(2) Image orthicons;

(3) SEC tubes; or

(4) Image dissectors.

The broad categories of vidicons and image orthicons include sensors with widely different mechanical and electrical characteristics.

The ultimate choice of sensor for this system must consider these characteristics:

(1) Sensitivity;

(2) Signal-to-noise ratio;

(3) Spectral response;

(4) Gamma;

(5) Signal uniformity;

(6) Resolution;

(7) Lag and "after-image";

(8) Signal storage;

(9) Stability of operation;

(10) Beam scanning irregularities;

(11) Power requirements;

(12) Physical size;

(13) Weight;

(14) Electrical-mechanical requirements of supporting circuits and components;

(15) Development status and availability; and

(16) Ruggedization.

Table 23 is a chart summarizing the major characteristics of the sensors considered for this camera; a discussion of these characteristics follows.

b. SENSITIVITY AND SIGNAL-TO-NOISE RATIO

A color television camera has an overall sensitivity lower than that of a monochrome camera using the same sensor and lens. This reduction is primarily the result of losses in the spectral filtering and the division of the available illumination between three sensors. The available illumination varies from 2 foot-lamberts (when viewing the astronaut's face inside the Apollo Command Module) to a maximum of 10, 000 foot-lamberts (when viewing highly reflective objects on either the earth or the moon with the sun's rays normal to the scene). Assuming an approximate loss of 200 : 1 for an f/2 lens, dichroics, and trim filters of the camera results in an available faceplate illumination of 0.01 to 50 foot-candles for the green or luminance channel. Only the SEC intensifier vidicon and image orthicon have adequate sensitivity for color pickup with an acceptable signal-to-noise ratio under the lower levels of illumination. The principal source of noise in cameras using either the vidicon or SEC sensor is thermal noise from the target load resistor. The signal-to-noise ratio is a function of the available illumination and can be greater than 40 db for higher illumination levels. The principal source of noise in image orthicon cameras is due to "shot" noise in the beam; however, the maximum signal does not increase indefinitely as in the case of vidicons but is limited by the "knee" characteristic of the image orthicon. The maximum signal-to-noise ratio which can be achieved with the 2-inch image orthicon cameras in the range of 30 to 35 db.

c. SPECTRAL RESPONSE

The spectral filter characteristics for red, green, and blue are shown in Figure 31. The selected sensor must have adequate sensitivity within these spectral regions. Figure 32 is a graph of the average spectral characteristics of three available photocathodes and photoconductors.

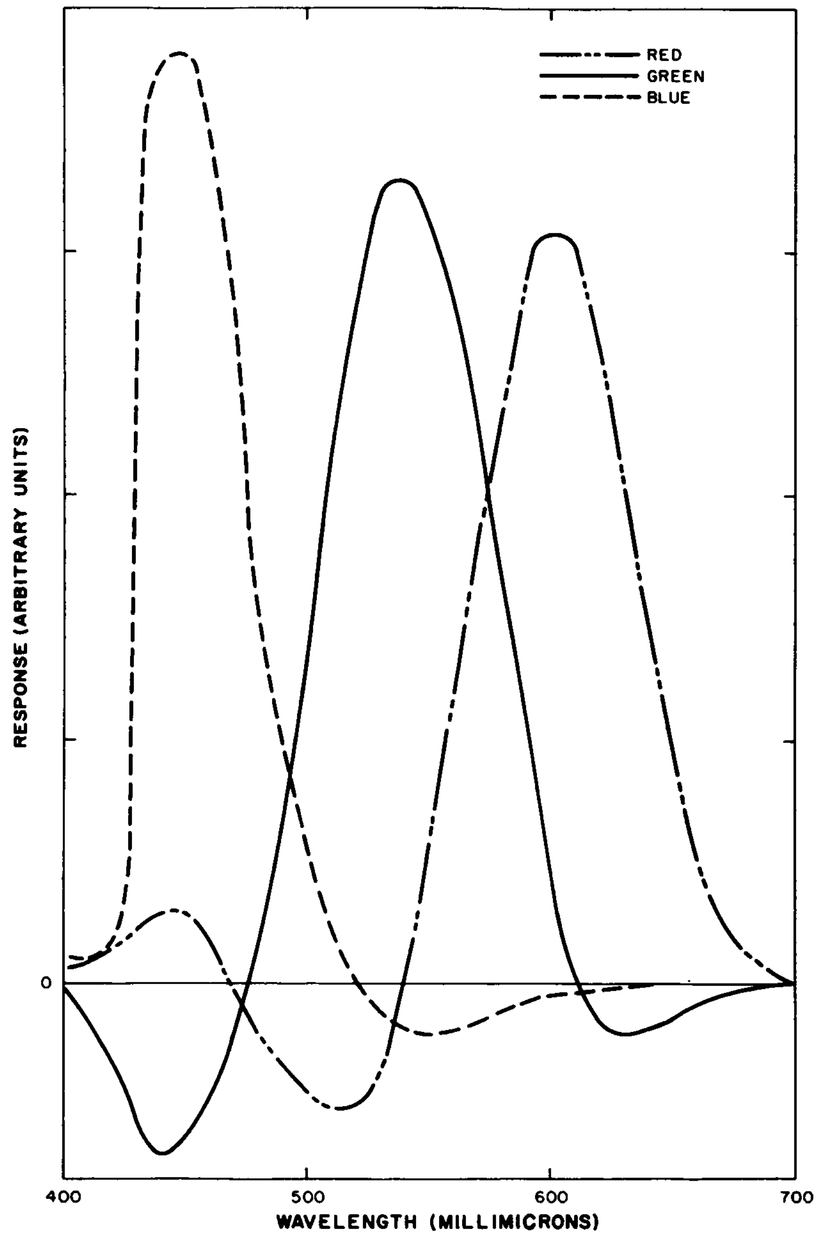


Figure 31. Idealized Spectral Response of Sensors

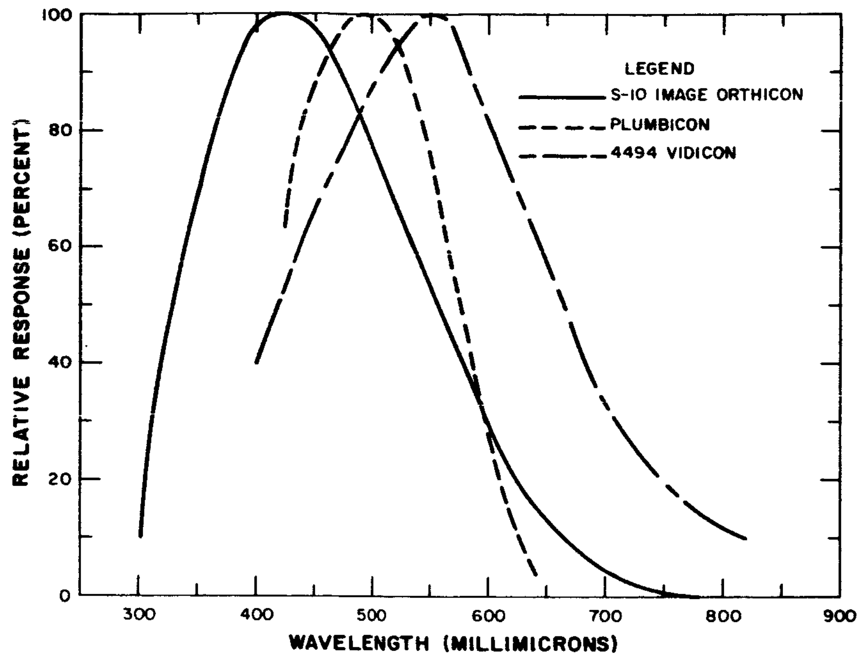


Figure 32. Average Spectral Characteristics of Three Available Sensors

d. RESOLUTION

A limiting resolution capability of 500 TV lines is required for normal live coverage, and a limiting resolution of 800 to 1000 TV lines is desired for color "stills". The sensor having the maximum amplitude response at 320 TV lines is desired for standard operation, with the minimum acceptable response being approximately 25 percent. The resolution capability of the sensors being considered is given in the chart in Table 23.

e. GAMMA

The gamma (γ) of a sensor defines its light versus signal current transfer characteristics. It is rigorously defined as:

$$\gamma = \frac{\log \text{(Signal)}}{\log \text{(Illumination)}}$$

It is desirable that the gamma of the sensor be less than unity. This characteristic allows the sensor to handle high illumination areas within the scene without becoming "beam-limited". Secondly, it is desirable that the gamma differential between the three sensors be essentially zero.

TABLE 23. COMPARISON OF SENSOR CHARACTERISTICS

Characteristic	Plumibcon 55875 (See Note 2)	RCA Vidicons 4493, 4494, 4495 (See Note 4)	1/2-Inch Selenicon (See Note 5)	1-Inch Selenicon (See Note 5)	3-Inch Image Orthicon C21020 (See Note 7)	Apollo SEC Vidicon (See Note 10)
1. Sensitivity (Required foot-candles for 60 nanoamperes) (See Note 3)	0.1	0.6	0.3	0.08	0.001	0.001
2. Maximum S/N Capability (db)	>40 (See Note 1)	>40 (See Note 1)	>40 (See Note 1)	>40 (See Note 1)	30 (at 0.05 ft-candles or greater)	36
3. Resolution						
a. Percent at 320 TV Lines	55%	15%	15%	45%	45%	18%
b. Limiting (TV Lines)	>700	500	500	800	500 (at 0.03 ft-candles)	600
4. Gamma	0.9 to 1.0	0.7	0.9 to 1.0	0.9 to 1.0	1 (below knee)	1 (approx)
5. Dark Current (nanoamperes)	<3	10	<3	<5	—	<3
6. Lag (after 3 frames)	<<5%	15% (See Note 6)	<10%	<15%	<<5%	<5%
7. After-image (after 3 seconds)	<<1%	3%	3%	3%	<<1%	<<1%
8. Signal Non-Uniformity	—	15%	20%	15%	15%	<25%
9. Spectral Characteristics	Peaks at 500 mμ; deficient in red	Peaks at 500 mμ; slightly different for blue channel	—	—	S-10; peaks at approx 450 mμ	S-20
10. Scan Format (Diagonal)	0.79 in.	0.32 in.	0.32 in.	0.625 in.	1.2 in.	0.625 in.
11. Lens F-No. for Equivalent Depth of Field	f 2.8	f 1.14	f 1.14	f 2.2	f 4.25	f 2.2
12. Profile Shift and Beam Bending	—	0.5%	0.5%	0.25%	—	—
13. Method of Deflection	Magnetic	Magnetic	Magnetic	Magnetic	Magnetic	Magnetic (scan section)
14. Method of Focus	Magnetic	Electrostatic	Electrostatic	Electrostatic	Magnetic	Electrostatic (scan section & image section)
15. Availability	6 to 8 month delivery	2 to 3 month delivery	Developmental estimated 1½ year	Developmental; estimated 1 year	Developmental; estimated 1 year	2 to 3 month delivery
16. Physical size (inches)	1-1/4 × 8-1/4	1 × 6-1/4	1/2 × 3	1 × 5-1/4	2 × 9-1/2	2-1/4 × 8-1/2
17 Ruggedized	No	No	No	Design exists	Goal: Jan 1967	Yes
18. Comments	(See Note 8)		(See Note 8)	(See Note 8)		(See Notes 8 & 9)

Notes

1. Vidicon transfer curve does not have an abrupt knee as does the image orthicon. Also, the principal noise source is the preamplifier. As a result, the maximum signal-to-noise ratio for the vidicon is a function of available illumination and beam current.
2. Data sheet dated June 1965.
3. Data is for 30 frames per second.
4. Data sheet dated November 1965.
5. Estimates based on discussion of goals.
6. At high light level conditions.
7. From tentative data sheet.
8. High gamma requires additional gamma-correction circuitry.
9. Requires 10-KV power supply for image section.
10. Specification for spacecraft TV camera image tubes.

f. SIGNAL UNIFORMITY

Signal non-uniformity or shading should be non-existent. If not, the non-uniformities must be corrected to an absolute maximum of 10 to 15 percent. The differential shading between sensors should be limited to less than 5 percent.

g. LAG AND AFTER-IMAGE

Lag and "after-image" are characteristics defining the percentage of video signal remaining on succeeding frames from a given frame. These characteristics are generally defined at two points. Lag is generally defined at broadcast rates as the percentage of video signal of the original scene observed at the third frame. After-image defines the number of seconds of scanning required for the video signal of the original scene to decay to the 3 to 5 percent point. The ideal sensor would read out completely in one scan (i.e., no lag or after-image). Available sensors have lag characteristics ranging from those approaching the ideal to 50 percent. The significance of lag and after-image can be appreciated when viewing a real time image of an object moving through the camera's field-of-view. A "tail" or smear will be observed following the object due to incomplete readout. In a color camera, the hue of this "tail" may change due to different values of lag for the individual red, green, and blue sensors.

This overall problem is compounded by the dependency of lag on brightness in some types of sensors. Generally, the higher the available illumination in the scene the lower the percentage of lag and after-image.

h. SIGNAL STORAGE

The target storage characteristics of the selected sensor must be adequate for the 1/7.5-second frame period. The target resistivity must be sufficiently high to (1) allow integration of the scene information without loss during the 1/7.5-second period between successive scans of any specific area of the scan format, and (2) eliminate any loss of resolution due to lateral leakage between adjacent resolution elements in successive scans.

Of the available sensors, the SEC vidicon has the best overall storage characteristics. However, photoconductors for broadcast rate color cameras are adequate for 7.5-frame-per-second operation, but marginal for the longer scan period required for color "still" operation. Slow-scan photoconductors such as the ASOS* will store an image for approximately 20 seconds.

* Antimony sulphide oxy-sulphide

i. BEAM SCANNING IRREGULARITIES

Registration problems associated with fixed non-linearities in the camera deflection can be corrected in the scan conversion process at the ground station. However, dynamic incremental registration problems associated with the scanning beam cannot be corrected externally and must be minimal in the selected sensor. Two such basic components associated with low-velocity read-out characteristics are beam bending and beam profile shift. Beam bending is the lateral deflection of the scanned beam near the target as influenced by potenials on the target. Beam profile shift is the variation in the distribution of electrons that enter into target readout (primarily as a function of signal level) as compared with the average distribution of the available electrons in the read-out beam. Both of these characteristics become significant when differential values exceed the limits determined by system resolution.

j. POWER REQUIREMENTS

The comparison of power requirements in the choice of sensor must include the sensor plus its supporting functions. For example, sensors requiring very high voltage or electron multiplication or magnetic focus, etc. will consume the largest amounts of power. A chart comparing the power requirements of various vidicons is given in Table 24.

k. WEIGHT AND PHYSICAL SIZE

The mechanical characteristics of weight and physical size are of prime importance. The restricted space available in either the Apollo Command Module or the LEM dictates a minimum size configuration. Similarly, the strict weight limitations, especially during the LEM lunar descent phase, impose minimum weight specifications for the sensor. As in the case of the power requirements, the weight and physical size characteristics of the sensor must include its unique supporting circuitry and components.

3. Evaluation of Image Sensors

a. GENERAL

Table 23 is a chart of the electrical and mechanical characteristics of the sensors being considered; Table 25 is a chart rating these sensors in relation to their application in the Apollo color camera. A numbering system of 1 through 5 is used to rate the sensors from "unacceptable" (1) to "excellent" (5) for the proposed application. A discussion of the sensors and how each relates to the Apollo color camera requirements follows.

TABLE 24. VIDICON POWER REQUIREMENTS AT VARIOUS ACCELERATING POTENTIALS

Type of Vidicon	Accelerating Potential (vdc)	Filament Power (mw)	Focus Power (mw)	Deflection Power (mw)	Alignment Power (mw)	Power to Generate Vidicon Voltages (mw)	Total Power (watts)
1-Inch Magnetic Focus, Magnetic Deflection	1000 500	800 800	2600 1300	500 375	50 50	1000 675	5.00 3.20
1-Inch Hybrid Electro-static Focus, Magnetic Deflection	1000 500	800 800	0 0	375 280	50 50	1000 675	2.22 1.80
1-Inch Electrostatic Focus, Electrostatic Deflection	1000 500	800 800	0 0	150 100	50 50	1000 675	2.00 1.63
1.5-Inch Electrostatic Focus, Magnetic Deflection	1400	800	0	500	100	1250	2.65
1-Inch Hybrid SEC, Electrostatic Focus, Magnetic Deflection	1000	800	0	375	50	2500	3.72

Notes:

1. All Power Requirements are based on power drawn from 24.5-vdc input
2. Filament power is for unregulated 6.3-vdc filament voltage

TABLE 25. COMPARATIVE RATING OF SENSORS

Characteristic	Plumbicon	RCA 4493 4494 4495	1/2-Inch Selenicon	1-Inch Selenicon	2-Inch Image Orthicon C21020	Apollo SEC Vidicon
Sensitivity	3	2	2	3	4	5
Spectral Response	3	4	4	4	4	4
Gamma	3	5	3	3	4	3
Signal Uniformity	4	4	3	4	4	4
Resolution (at 7.5 frames/sec)	4	3	3	4	4	3
Lag and After-Image	5	3	5	5	5	5
Signal Storage	3	4	4	4	3	5
Stability of Operation	5	5	5	5	3	4
Beam Scanning Irregularities	*	3	3	4	4	*
Power Requirements	3	5	5	5	2	3
Physical Size and Weight	2	4	5	4	1	3
Development Status	5	5	2	3	4	5
Ruggedization	1	4	3	4	3	4
Color "Still" Capability	*	2	*	*	3	3

Rating: 1. Unacceptable
2. Marginal
3. Average
4. Above Average
5. Excellent

Notes: *Denotes No Information Available

b. PHOTOCONDUCTOR VIDICONS

The conventional vidicon is the most attractive of the sensors evaluated in terms of size, weight, minimum complexity, and external circuitry and components required. In addition, it is generally available in a ruggedized configuration. Four basic vidicon configurations have been considered: (1) the 1/2-inch hybrid, (2) the 1-inch hybrid, (3) the 1-inch all-magnetic, and (4) the 1-inch all electrostatic.

(1) The 1/2-Inch Hybrid Vidicon

The 1/2-inch hybrid is the optimum package configuration available. Figure 33 is a possible camera configuration using this 1/2-inch vidicon. Having external dimensions of only 1/2-inch diameter by 3 inches long, and requiring only a small lightweight yoke, it presents the smallest and lightest configuration available. However, the 1/2-inch format is deficient in these areas:

(a) Its resolution is approximately 500 TV lines, which is adequate for standard operation but not adequate for color "stills;"

(b) Its sensitivity is approximately one-third that of a 1-inch configuration with the same f-number; and

(c) Beam bending and beam profile shift is more of a problem when scanning small formats.

(2) The 1-Inch Hybrid Vidicon

The 1-inch all-electrostatic vidicon was eliminated from detailed evaluation in favor of the 1-inch hybrid. The 1-inch hybrid offers the following advantages compared to the all-electrostatic:

(a) The limiting resolution is higher than that of the all electrostatic vidicon;

(b) The magnetic-deflection method affords more latitude in the design of the electronics for this application, although the power required by the two deflection methods is comparable when considering the complete circuit.

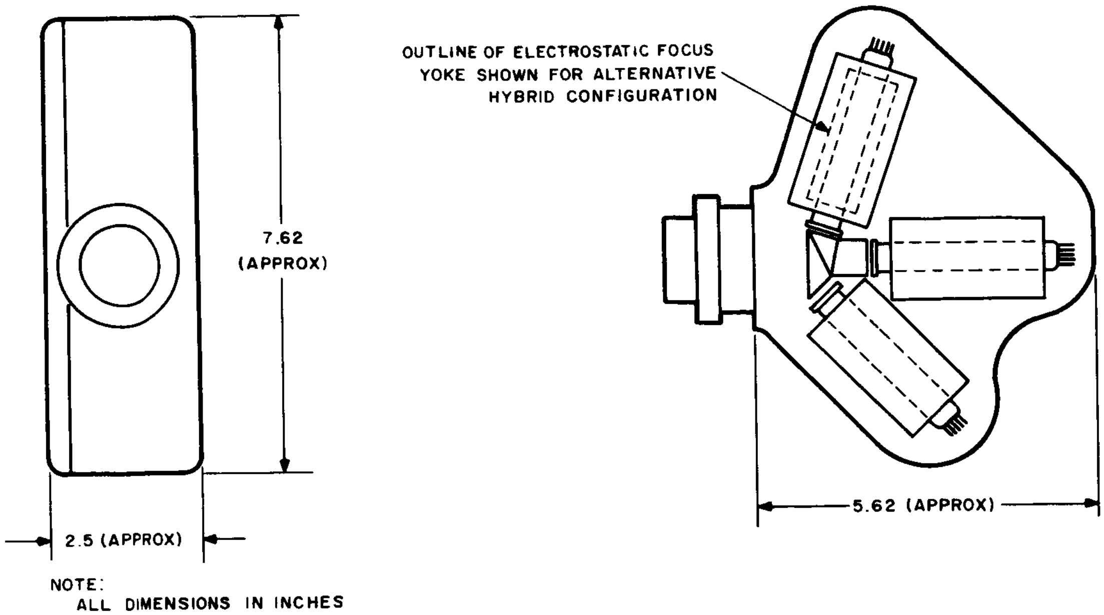


Figure 33. Package Outline for Camera Head Using Three All-Magnetic 1/2-Inch Vidicon Tubes

The 1-inch hybrid has the following advantages and disadvantages compared to the 1/2-inch version.

Advantages:

(a) Better resolution capability (although it is still not as high as desired for color "still" operation) ;

(b) More sensitive than the 1/2-inch version with lens of the same f-number;

(c) Better beam bending and profile shift characteristics; and

(d) A space-qualified gun is available.

Disadvantage:

(a) Increased weight and volume.

(3) The 1-Inch All-Magnetic Vidicon

A possible camera configuration using the 1-inch hybrid vidicons is shown in Figure 34. The 1-inch all-magnetic vidicon has the resolution capability to satisfy the color "still" requirement. Its major disadvantage is the increase in size, weight, and power requirements, resulting from the use of an external magnetic focus coil assembly. In deciding whether to use the 1-inch all-magnetic or the 1-inch hybrid, the size and weight disadvantages should be weighed very carefully against the requirement for 800 to 1000 TV lines, which is the limiting resolution desired for color "stills".

The choice of photoconductor for the type of vidicon selected presents a major problem. The ideal photoconductor has high sensitivity, no dark current, no lag or after-image, adequate lateral resistivity and satisfactory spectral response. Existing porous photoconductors used in monochrome applications are quite "laggy" except under high illumination conditions. Also, dark current is considerably higher than desired to minimize shading. Of presently available photoconductors, lead oxide used in the Plumbicon made by Phillips of Eindhoven, Netherlands and distributed by Amperex Electronic Co., Hicksville, New York, has characteristics which meet many of the requirements. This photoconductor has practically no dark current, and negligible lag and after-image characteristics. Its disadvantages are:

(1) Insufficient lateral resistivity to provide adequate resolution in the color "still" mode and some loss in amplitude response at 7.5 frames per second;

(2) Low yield of red-sensitive surfaces; and

(3) A gamma of unity, which requires additional external gamma-correction circuitry.

The major problem associated with using the Plumbicon in the Apollo color camera mission is its physical configuration. The present tube is an unruggedized all-magnetic vidicon having external tube dimensions of 1-1/4 inches by 8-1/4 inches. The resulting camera size and weight would be prohibitive for the Apollo mission. Contact with the Plumbicon distributor has revealed no intention at this time either to ruggedize of design a smaller configuration for the Plumbicon-type vidicon.

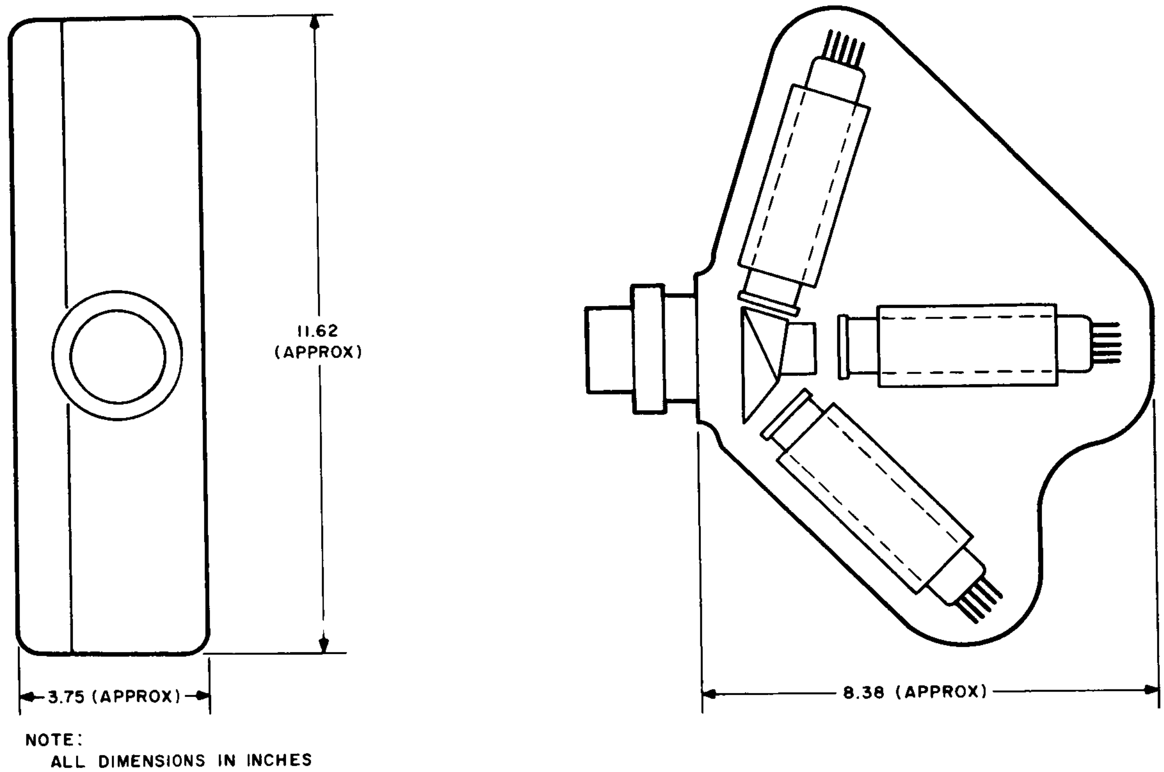


Figure 34. Package Outline for Camera Head Using Three 1-Inch Vidicon Tubes with Electrostatic Focus

RCA has announced a new vidicon which is to be used in their TK-42 color camera. This tube is called the "Selenicon". While the actual characteristics of this sensor are not published it has been stated that it is for color application and is to compete with the Plumbicon. Also, the Selenicon will be constructed in the 1-inch hybrid configuration. Assuming that the design goals are met, the Selenicon might well be the optimum choice for the Apollo color camera. Its obvious major disadvantage is its development status. It is recommended that the status of this sensor be monitored very carefully prior to the choice of sensor for the Apollo color camera. If the Selenicon meets its present design goals, it should be the overall optimum choice.

An interim choice of 1-inch hybrid vidicons for color application are the 4493, 4494, and 4495 RCA vidicons (selected for the red, green, and blue channels, respectively). This series of vidicons is essentially based on selected units of the standard porous photoconductor. Certain modifications of the gun have also been performed to minimize beam bending and profile shift characteristics. In addition, the scan format has been reduced in size from the standard 1-inch scan area in order to reduce lag and dark current. As a result of this reduced scan area, the sensitivity and resolution are more comparable to that of a 1/2-inch vidicon than a normal 1-inch size. The electrical performance characteristics of the 4490 series do not meet the desired goals in sensitivity, resolution, lag, and dark current; however, they are the only available series of vidicons in the one-inch hybrid configuration which are specifically tailored for color application. The Selenicon when developed will use the same tube configuration and should require no major camera modification other than a larger (standard) scan format to replace the 4490 series.

c. IMAGE ORTHICONS

Generally, image orthicons have been favored over other sensor types or configurations for use in color cameras. As a class, image orthicons are more sensitive than vidicons, but are usually much larger and complex. The major advantages and disadvantages of image orthicons as compared to vidicons are:

Advantages:

(1) More sensitive than vidicons; and

(2) Low lag and dark current.

Disadvantages:

(1) Larger and more complex than vidicon (image orthicon has both an image section and an electron multiplier);

(2) Lower maximum signal-to-noise ratio than vidicon due to "knee" in transfer characteristics; and

(3) Resolution lower than vidicon for comparable scan format size.

The 2-inch all-magnetic image orthicon was evaluated for the Apollo color camera system. While this tube is attractive for the lower illumination levels found in the Apollo Command Module, it results in a very heavy and bulky camera package. It is estimated that a three-tube 2-inch image orthicon camera would weigh more than 20 pounds without optics and would occupy a minimum volume of 1000 cubic inches. Finally, the circuit requirements imposed by the image orthicon's image section and electron multiplier result in a more complex and less stable camera. For these reasons, the image orthicon is not considered suitable for the Apollo color camera.

d. IMAGE DISSECTOR

The image dissector is similar to, but simpler than, the image orthicon. Fundamentally, it consists of a photocathode and an electron multiplier. Having no target, it does not possess any storage capability. Its major assets are relative simplicity and no lag. In addition, its signal-to-noise ratio is mainly a function of the photon-induced electron stream from the photocathode. The number of electrons (N) emitted from the photocathode is proportional to light level; the noise is proportional to the square root of N and therefore decreases as the light level is decreased. The result is a larger dynamic range for the image dissector compared to vidicons or image orthicons. Image dissectors can be procured in almost any size that is desired. The major limitation of this tube and the feature which eliminates it from further consideration for this application is poor sensitivity, compared to the vidicon, when operating at 7.5 frames per second or faster. As mentioned, the image dissector has no storage; therefore, the video signal available is that signal which is being instanteously emitted from an element of the photocathode as it is "scanned" by the multiplier entrance aperture. A 1-inch diameter image dissector package that would be suitable for the Apollo color camera would have a maximum signal-to-noise ratio of approximately 16 db.

e. SEC VIDICON

The SEC vidicon is a relatively new image sensor. It has a high-voltage photocathode image section which images electrically on an SEC target of potassium chloride. Readout is performed from the target with a conventional low-velocity vidicon beam. The major disadvantages and advantages of the SEC vidicon are:

Advantages:

(1) Up to 100 times more sensitive than a standard vidicon;

(2) Essentially no lag or after-image; and

(3) Large dynamic range with adjustment of image section voltage.

Disadvantages:

(1) Larger than the 1-inch vidicon;

(2) Requires 8 to 10 kv for operation of image section; and

(3) Lower resolution compared to a vidicon of equivalent scan format size.

The SEC configuration used in the present monochrome LEM television camera represents the next step in size and complexity compared to the standard 1-inch vidicon. In relation to the requirements of the Apollo color camera, it is very attractive in terms of sensitivity and no lag or after-image.

Final selection of an SEC versus a 1-inch vidicon must consider the better signal-to-noise ratio of the SEC when operating in the light-limited Apollo Command Module environment versus the larger, heavier, and more complex camera required with the SEC.

Figure 35 is a possible camera configuration using three SEC vidicons.

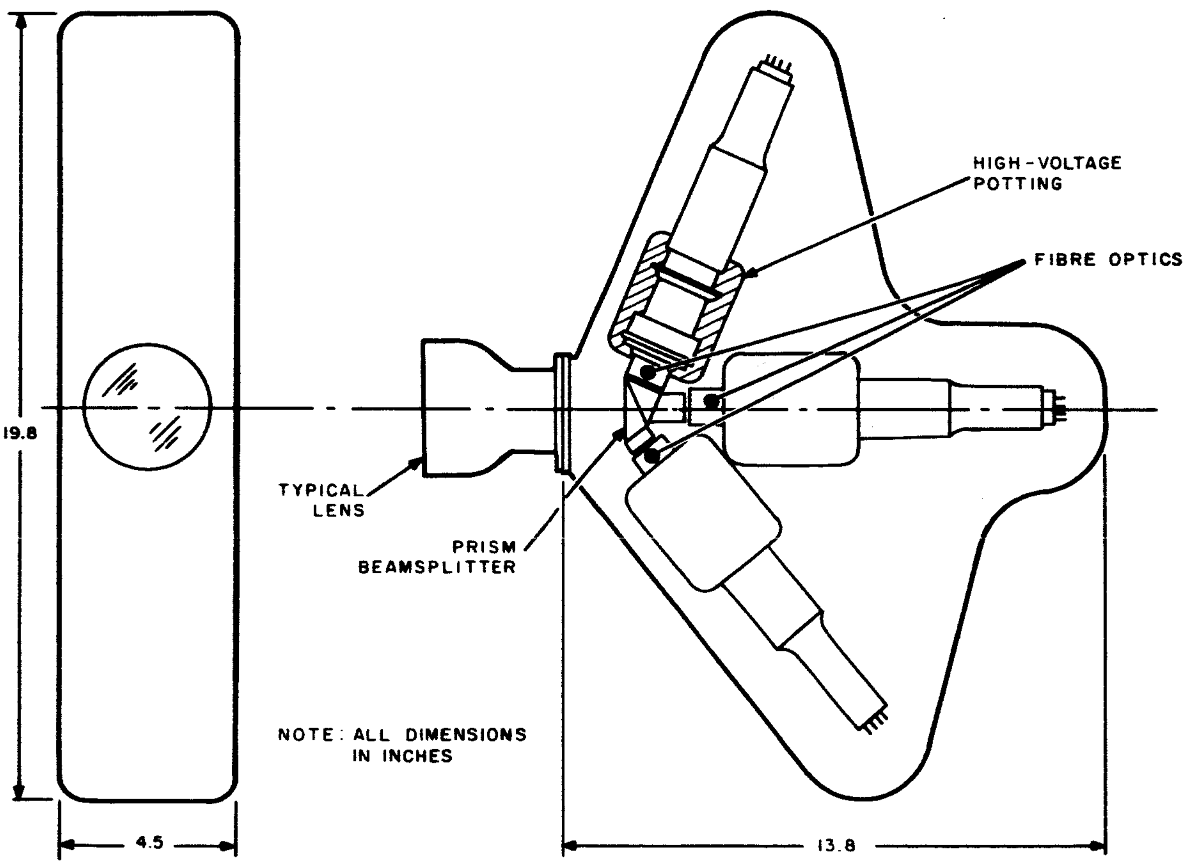


Figure 35. Package Outline for Camera Head Using Three SEC Tubes

f. CONCLUSIONS

A great deal of work is presently going on in the image tube industry to develop vidicons that yield high-quality broadcast video. To this end, Phillips has developed the Plumbicon, and other companies, including RCA, are working on photoconductor developments. One such tube is RCA's Selenicon with a 1-inch hybrid gun.

Other tubes such as the SEC vidicon, image orthicon, and intensifier vidicon are excluded from serious consideration for the hand-held 3-tube motion picture camera because of the resultant size and power requirements of the camera. These restrictions, in turn, limit the use of the camera to situations where the incident scene highlights have a value of approximately 60 foot-lamberts or higher.

The high-resolution slow-scan mission requires a sensor with reasonable aperture response at 1000-TV-line resolution. This requirement limits the available tubes to large scan-area SEC vidicons, 1-inch all-magnetic vidicons, or the 1.5-inch hybrid vidicon with ASOS* or similar photoconductor. The Plumbicon photoconductor has lateral leakage rates that make it unacceptable for slow scan rates and even questionable for 7.5-frame-per-second operation.

The Apollo Pallet ultra-high resolution application is based on the use of the 4.5-inch return-beam vidicon and the ASOS photoconductor.

Table 26 is a summary of the missions considered in this study and the sensor proposed for each.

4. Optical Considerations

a. GENERAL

This portion of the report deals with the photometric environment as well as the optical design considerations involved in the space color camera application. Many of the optical factors relevant to the existing monochrome television mission on Apollo-LEM are also relevant to the color television application. The primary difference being the higher light levels required for the color camera, due to splitting the light into three paths, and the transmission loss through the filters and added optical components.

* Antimony sulphide oxy-sulphide

TABLE 26. SUMMARY OF PROPOSED SENSORS

Mission	Sensor	Primary Reasons for Choice
Hand-Held Motion Picture TV Camera with broadcast quality video	1-inch hybrid vidicon with SPS photoconductor or Selenicon photoconductor when available.	1. Ruggedized tube design available. 2. Considerable industry effort on improving photoconductor. 3. Allows practical-size and -weight camera.
Lunar-Surface Still-Camera, 1000 TV-line resolution	1.5-inch hybrid vidicon with ASOS photoconductor or equivalent.	1. Expect ruggedized design within year. 2. Has the optimum size and weight with the potential of improving.
Natural-Resources High-Resolution Camera Apollo Pallet	Return-beam vidicon in 4.5-inch image orthicon bottle and ASOS photoconductor.	1. Only tube with sufficient resolution. 2. Space qualification and ruggedization may be promoted by other space programs as well.
Low-Light-Level Motion Picture TV Camera with broadcast quality video (not hand-held)	1-inch hybrid SEC vidicon	1. Tube presently being space-qualified. 2. Minimum size and weight for low-light-level application.

b. LUNAR SURFACE

On the lunar surface, maximum luminance will approach 13,000 foot-candles when the camera views the LEM or astronauts in direct sunlight. The moonscape itself is expected have relatively low reflectivity, as indicated by the Ranger and Cosmos pictures of the lunar surface; therefore, scenes containing the astronaut will have a wide dynamic range, and good pictures of the astronaut will be at the expense of showing a dark background.

Very little is known about the color characteristics of the moon. The major portion of the lunar surface is expected to present a monochrome scene; however, very small areas of color have been seen by most selenographers. Most of these colorings are faint, sometimes transient, and are seen only at certain lunar phases and illuminations. The surface colors fade and darken with changes in solar radiation, and appear to vary during the course of the lunar day. Faint reds, yellows, browns, and greens have been seen from earth-borne telescopes.

The lunar surface is neither perfectly diffuse nor specular. The apparent color and brightness is a function of line-of-sight angle with respect to the surface normal and the angle of incident illumination with respect to the camera angle. There is good reason to expect the lunar surface to have colors comparable to the colors of rocks on earth.

c. EARTH-ORBIT LUNAR-ORBIT

The view from the Command Module window will allow color television coverage of the earth and moon with the hand-held motion picture camera. Also, it will be possible to take high-resolution pictures from an externally mounted camera on the Apollo Pallet as discussed in Section IIIE.

The extreme range of illuminance in which the camera must operate is indicated in the following list of photometric environments.

Environment	Illumination (foot-candles)
Spacecraft in Earth Orbit:	
Earth in direct sunlight:	13,000
Earth in moonlight:	10^{-2} to 10^{-3}
Earth in starlight:	10^{-4} to 10^{-5}
Spacecraft in Lunar Orbit:	
Moon in direct sunlight:	13,000
Moon in earthshine:	1.7
Moon in starlight:	10^{-4} to 10^{-5}

The maximum values will be reduced by the reflectivity of the scene and the photometric function for a given camera aspect. At the other extreme, ambient levels other than sunlight will be too low for orbital earth or lunar pictures.

The albedo of the earth varies from 90 percent for some clouds down to about 1 percent for the ocean and plowed earth. The albedo of the moon averages about 7 percent, but as viewed from the earth, the moon has highlights that reach 40 percent reflectivity. In pictures of the earth, the clouds will be approximately 200 times the minimum sensitivity of the color camera. The greatest difficulty will be the dynamic range in the scene, i.e., approximately 100 to 1. It will be necessary to let the camera saturate on the clouds in order to get good pictures of the earth. Photography of the moon will not be as difficult since the maximum contrast is lower, i.e., approximately 40 to 1.

d. LIGHT LEVELS FOR COMMAND MODULE

Recent experience with the Apollo Command Module monochrome television camera has revealed the complex and detrimental characteristics of the existing interior illumination.

All illumination is generated by fluorescent lights. These lights, when viewed directly, have a luminance of about 2000 to 3000 foot-lamberts. Typical scene highlights of interest, such as the astronaut's face, have an illuminance of approximately 2 foot-lamberts, but the limited size of the Command Module interior makes it impractical to take pictures without viewing the lights also. It appears that the only practical solution is to accept the bright "globs" in the display, which result from video signal saturation. On the positive side, it appears that the highlights in the scene of interest within the Command Module will be reasonably constant, thus there will be little need for a wide dynamic range for this particular application.

The 2-foot-lambert scene highlight is near the lower design limit for the existing monochrome vidicon camera (30- to 40-db signal-to-noise ratio). This signal-to-noise ratio is achieved with the vidicon operating at a relatively high target voltage.

There appears to be little chance of appreciably increasing the ambient illumination in the Command Module. One of the main constraints is the heat generated by the lamps.

The three-tube vidicon camera requires a minimum scene highlight of 60 foot-lamberts to assure a 34-db picture. The alternative is to use sensors such as the SEC vidicon, intensifier vidicon, or return beam vidicon. These sensors, as shown in Figure 35, require a package size that is bulky for hand-held operation and presents other problems in storage and bulkhead mounting.

The Command Module application presents a seriously conflicting requirement. The camera head must be small, yet the scene highlight is low for normal color television photography. Mounting a floodlight on the camera has been considered. The floodlight would be turned on only when color pictures are being taken, similar to the use of camera-mounted floodlights for home movie cameras. While the power is probably available for such a light, it would have a blinding effect on the astronauts within the Command Module. This short-term loss of sight is a high price to pay for color television coverage. The heat from the lamp creates an added hazard in that the astronaut could be inadvertently burned.

There appears to be no practical solution to the problem. It is felt that the benefit to be obtained from color television coverage within the Command Module should be weighed carefully against the shortcomings of modifications to the existing configurations.

e. ARTIFICIAL ILLUMINATION REQUIREMENTS

Proper operation of the television system will require the use of artificial illumination when lunar highlights are less than 60 foot-lamberts. Since the mean illumination of the moon by the full earth is 1.7 foot-candles, all zones of lunar interest other than sunlit areas will require illumination. To determine the amount of illumination needed, let us assume a situation where the astronaut is involved in activity in front of nearby lunar topography, where it is desirable to illuminate the entire area to obtain a complete detailed picture of the activity and the background. A reasonable set of conditions are as follows:

(1) Absence of all useful natural illumination;

(2) Lunar background within 20 feet of the camera with an area of 10 feet by 10 feet;

(3) Required scene highlight is 60 foot-lamberts; and

(4) Characteristics of the lunar surface are:

(a) Reflectivity $R = 0.1$

(b) Photometric function $\phi = 0.8$

The light required on the background lunar topographical surface is

$$60 \text{ foot-candles} \times 10 \text{ feet} \times 10 \text{ feet} = 6000 \text{ lumens}$$

Because of the lunar photometry characteristics, the required light output F from the illuminator is:

$$F = \frac{6000}{R\phi} = \frac{6000}{(0.1)\ (0.8)} = 75,000 \text{ lumens}$$

Illuminator sources considered were filamentary types, such as photoflood and sun-arc lamps; compact arc-type lamps with xenon, mercury, and mercury-xenon as the filling gas; and flash tubes. The filamentary DXB photoflood was chosen as the illuminator with the best characteristics for this requirement. This illuminator, a special version of an incandescent lamp, is designed to produce very high levels of light at controlled color temperatures of about 3400° K. These high color temperatures are obtained by designing the lamps to operate at very high efficiencies (in the vicinity of 34 lumens/watt). At this high efficiency, the lamp life tends to be very short as compared to regular incandescent lamps. The photoflood lamp includes an iodine regenerative getter, which prevents wall blackening and maintains approximately full light output and color temperature throughout lamp life. The characteristics of the DXB photoflood lamp are as follows:

Input	500 watts, 120 volts
Average Life	6 hours
Light Output	50, 000 lumens
Beam Reflector	20-degree field, 0.8 efficiency
Size	5-inch diameter, 6-1/2 inches long

Lamp heat can be radiated to the lunar surface by means of an appropriate sink.

With the lunar background at a distance of 20 feet, this source will illuminate a circular area of 50 square feet at an intensity of 1000 lumens/ft^2. This illumination will produce a luminosity from the lunar background of 64 foot-candles/ft^2 which is enough to meet camera light level requirements.

f. ORBITAL IMAGE SMEAR

In order to obtain pictures from the Command and Service Module with the motion picture camera, the problem of image smear must be considered. There will be smear due to the incomplete erasure of the previous image, and smear due to the relative motion between the camera and scene during the frame time. This relative motion is due to the velocity of the spacecraft, both angular and translational, as well as movement by the camera operator in the case of hand-held operation.

Image smear is near zero when the optical axis of the camera is aligned with the velocity vector of the spacecraft. In orbit around the earth or moon, worst-case conditions apply since the camera angle is 90 degrees from the velocity vector. Analysis indicates that a 1/2-line smear decreases the image spatial frequency response by 10 percent and 1-line smear decreases the response by 50 percent. From these criteria, a smear limit of 1.0 TV line has been chosen as the basis for determining the maximum exposure time allowable before smear becomes intolerable.

A quantitative evaluation of smear may be obtained by first determining the orbital velocity of the spacecraft, and using this velocity to determine the ground distance covered in one frame time. For a circular orbit:

$$V = \sqrt{\frac{G_M}{R}} \left[1 + \frac{h}{R}\right]^{-1/2}$$

where

V is the orbital velocity, km/sec;

G_M is the gravitational constant, which is
4.0×10^5 km^3/sec^2 (earth) and
4.9×10^3 km^3/sec^2 (moon);

R is the radius, which is
5377 km (earth) and
1738 km (moon);

h is the orbital altitude, which is
556 km (earth) and
128 km (moon)

The ground velocity of the spacecraft in earth orbit is approximately 4 nautical miles per second, and in lunar orbit is 0.9 nautical mile per second. At 7.5 frames per second, the spacecraft in earth orbit covers a distance on the ground of 4/7.5 nautical miles in one frame time. This distance corresponds to one resolution element in the picture.

In order to limit smear to one resolution element in the picture, the camera field of view must be at least

$$\theta = \frac{\Delta dk}{h}$$

where

θ is the camera field of view;

Δd is the ground distance corresponding to one resolution element;

k is the resolution elements per frame; and

h is the orbital altitude.

Using values of

$$\Delta d = 4/7.5 \text{ nautical miles}$$

$$k = 300 \text{ resolution elements per frame}$$

$$h = 300 \text{ nautical miles}$$

yields a camera field-of-view from an earth orbit of

$$\begin{aligned} \theta &= \frac{(4/7.5) \times 300}{300} \\ &= 4/7.5 \text{ radian} \\ &= 31 \text{ degrees} \end{aligned}$$

For a lunar orbit

$$\Delta d = 0.9/7.5 \text{ nautical miles}$$

$$h = 80 \text{ nautical miles}$$

and

$$\begin{aligned} \theta &= \frac{(0.9/7.5) \times 300}{80} \\ &= 0.45 \text{ radian} \\ &= 26 \text{ degrees} \end{aligned}$$

g. COLOR SEPARATION SYSTEMS

The optical system for a color camera must split the incoming light into its red, green, and blue components. The method commonly used in three-tube broadcast color cameras, such as the TK-41, is shown in Figure 36. The dichroic mirrors pass the major portion of the color of interest and reflect the rest. Trim filters are then used for the final spectral tailoring. This filter system is relatively efficient since all of the green light (less absorption losses) falls on the green channel sensor, blue on blue, and red on red. The main disadvantage in using this optical system for space color cameras is the weight and bulk of the resultant package.

The use of prisms as in the Phillips Plumbicon camera, affords a more compact and rugged separation system. A functional diagram of this three-color system is shown in Figure 37. The beam splitter is composed of three separate prisms. The light entering from the lens passes into the first prism and strikes a dichroic coating on the back surface of this prism which reflects the blue component of the light. The angle of reflection is such that the reflected blue light is totally reflected at the first surface of this prism. A second dichroic surface, applied between the second and third prisms, reflects the red component. The reflected red light is again reflected at the first surface of the second prism due to a small air gap maintained between the first and second prism. The angle of reflection at this air-glass transition is such that the red component is totally reflected. The green light travels through the prisms without reflection and passes to the sensor designated to receive the green component. Color trim filters will be necessary between the last surface of each prism and the sensor faceplates. A facility to introduce neutral density filters will be included. The advantages of using the prism beam-splitter for a three-tube color system instead of the more conventional first surface mirror system are:

(1) The compact and rugged arrangement allows a smaller camera package. The prisms occupy a space of 1 × 2 × 3 inches and weigh about 0.3 lb.

(2) The prisms eliminate the inherent problem of spurious reflections and ghost images associated with dichroic mirrors.

(3) The small angles of incidence of the light on the dichroic surfaces minimize color errors.

(4) The prism system is more reliable and easier to maintain; the mirrors exhibit surface degradation when exposed to atmospheric contamination.

(5) Temperature effects on prisms are negligible, whereas mirrors are prone to distortion and deflection due to thermal expansion.

(6) An all-glass (as opposed to air or vacuum) optical axis reduces the long back (vertex) focal length required between the lens and the sensor by a factor of greater than two to one.

The optical system components should be mounted on a common baseplate which will locate and optically register the lens, relay optic, prism assembly, and sensor. The advantages of this method of mounting are:

(1) The common baseplate allows accurate alignment of the system, and thus overcomes the optical alignment problems associated with correct registration of images in a beam-splitting system.

(2) The baseplate minimizes displacements due to vibrations in the system, and thus prevents degradation of the images.

(3) The baseplate can be designed to compensate for deviations due to thermal variations.

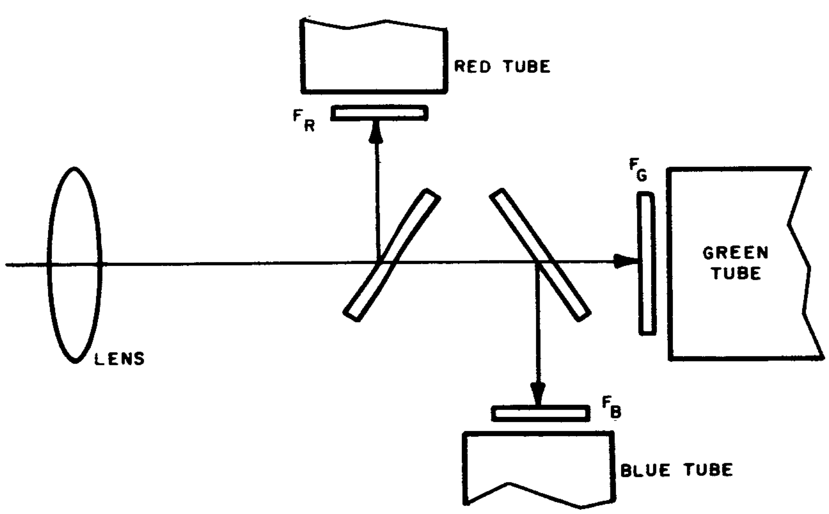


Figure 36. Three-Tube Color Separation System

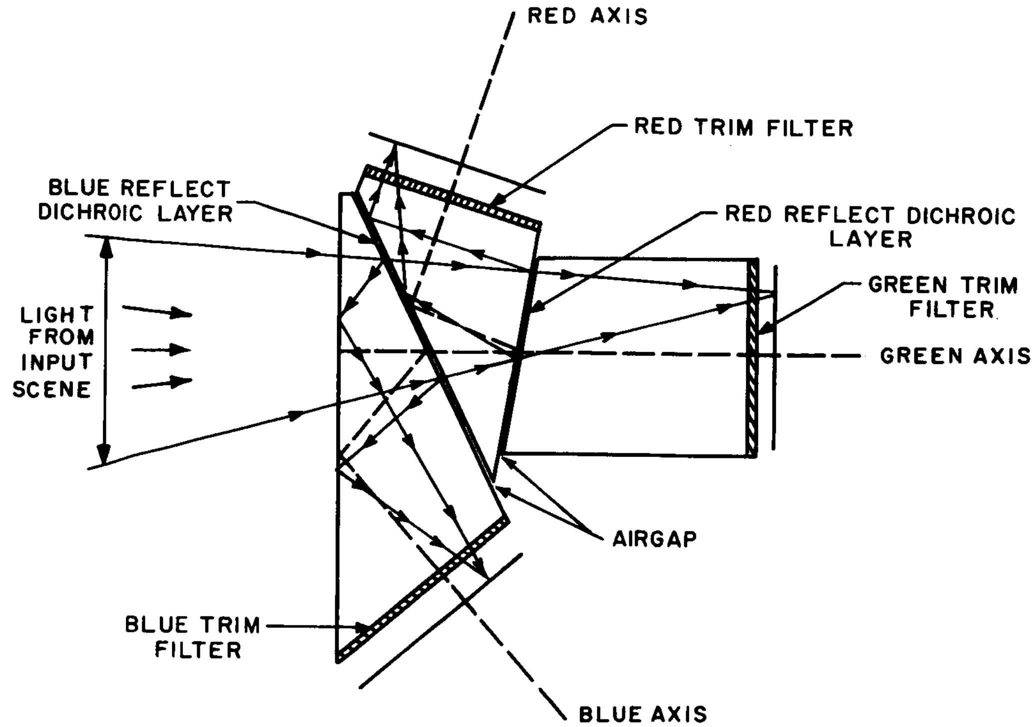


Figure 37. Three-Tube Color Separation System Using Prisms

Color separation in color filtering dispersion prisms, as described, has inherent light losses like any conversion system. The system utilizes dichroic-interference-type color filters which are very efficient in their primary transmission-reflection function; that is, the filter absorbs very little of the incident light bundle. However, the skirts of the spectral selectivity curves of the blue- and red-reflecting dichroic cubes overlap to such an extent that the adjacent green band is spectrally attenuated. In addition, optical and spectral filters are required to shape the transmission channels for correct tristimulus colorimetry. These filters cause further optical attenuation of all channels. The optical transfer loss through the color filters is severe; typical transmission factors based on sensors with an S-10 spectral characteristic are:

Blue filter transmission factor	5%
Green filter transmission factor	10%
Red filter transmission factor	18%

Chromatic aberrations of the lenses will be of no consequence if sensor displacement is adjustable. This capability will be of the utmost importance for the 1000-line resolution still pictures.

h. LENSES

The taking lens requirements are to a great extent a function of the particular mission and the type of color dispersion system used. The dichroic prism shown in Figure 37 has been selected as the optimum dispersion system; therefore, the discussion is limited to those lenses that will work with this system.

The Phillips Plumbicon camera has a 20-mm prism on the 1.25-inch Plumbicon image tube. This particular unit requires a lens back-focal distance of 67 mm, and is designed to work with a special zoom lens: the Angenieux 10:1 zoom, type 10X18E, 18 mm to 180 mm focal length.

The 1-inch vidicon has an image diagonal of 16 mm. In this case, it is estimated that the back focal distance for the taking lens must be a minimum 45 mm. The back focal distance is no particular problem in narrow-angle lenses because the lens design provides a long focal length and, in most cases, a long back focal distance. However, the back focal distance is a problem in wide-angle lenses. A relay lens or lens element must be added to the wide-angle lens in order to extend the back focal distance.

The lenses selected for the Apollo-LEM monochrome missions provide a good indication of the lens requirements for the color television missions. The parameters for these lenses are listed in Table 27; other lenses that are applicable, based on prior use in space, are also listed. The Argus 8.1-mm, the Fairchild 9.5-mm and the Fairchild 25-mm lenses will require modification to obtain the required back focal distance. Additional information about the Argus zoom lens is presented in Table 28.

The need to develop lenses specifically for the manned space program has been demonstrated by the lens development programs at Argus and Fairchild. Since these lenses are available and offer a reasonably wide selection of fields of view, it does not appear necessary or practical to explore the possibility of using commercial lenses for the color application. The Ranger lenses are considered because of their past qualification record. The 76-mm lens used in Ranger may be a good choice for the high-resolution "still" camera. The frequency response of this lens is shown in Figure 38. The El-Nikkor 63-mm, f/3.5 lens is a commercial lens that has excellent spatial frequency response, 55 percent at 40 cycles per millimeter. Since this lens is not qualified for space use, the Bausch and Lomb Super Baltor appears to be the optimum choice for the high-resolution camera. The response curves for the Argus and Angenieux lenses are presented in Figures 39 and 40.

TABLE 27. PARAMETERS OF AVAILABLE SPACE-QUALIFIED LENSES

Lens	Diagonal Angular Coverage (degrees)	Focal Length (mm)	f No.	Weight (ounces)	Size (inches)
Apollo Lenses					
Argus Wide-Angle+	80	8.1	1.9	3.5	2-3/4 × 1-3/4 dia.
Argus Zoom Lens*	8 to 34	20 to 76 (effective)	2	31	8 × 3 dia.
Ranger Lenses					
B& L Super Baltor	11.5	76	2	—	3-1/2 × 1-1/2 dia.
Angenieux **	39	25	0.9	—	1.8 × 1.6 dia.
LEM Camera Lenses					
Fairchild Wide-Angle Command Module	72	9.5	0.7	—	—
Telephoto	8	100	—	—	—
Lunar Day Lens Narrow Aperture / Lunar Night Lens Wide Aperture	33	25	1.04	—	—

Notes: + See Figure 39
* Refer to Table 28
** See Figure 40

TABLE 28. MODULATION TRANSFER FUNCTION OF THE ARGUS ZOOM LENS (20 to 76 mm, f/2)

Focal Length		Percent Response
20 mm	On Axis	97
	Off Axis (1/2 angle) 17 degrees	77
55 mm	On Axis	96
	Off Axis (1/2 angle) 6.25 degrees	95
76 mm	On Axis	97
	Off Axis (1/2 angle) 4.5 degrees	96
Note:	These data were taken at 20 lines/mm (211 TV lines) with the lens stopped down to f/8 and focused at infinity. The lens performance has been optimized at f/8. The zoom is knob controlled, but it could very easily be powered with a motor.	

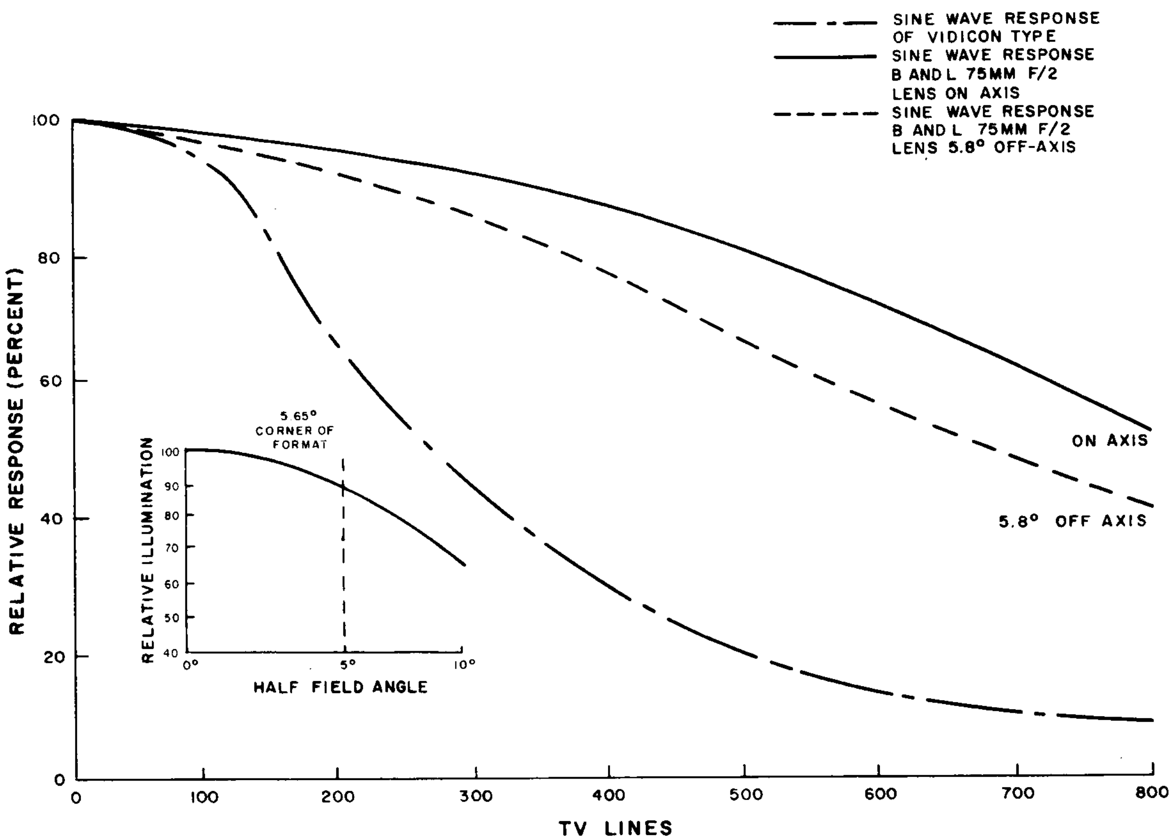


Figure 38. Sinewave Response of Bausch and Lomb 76-mm, f/2.0 Lens

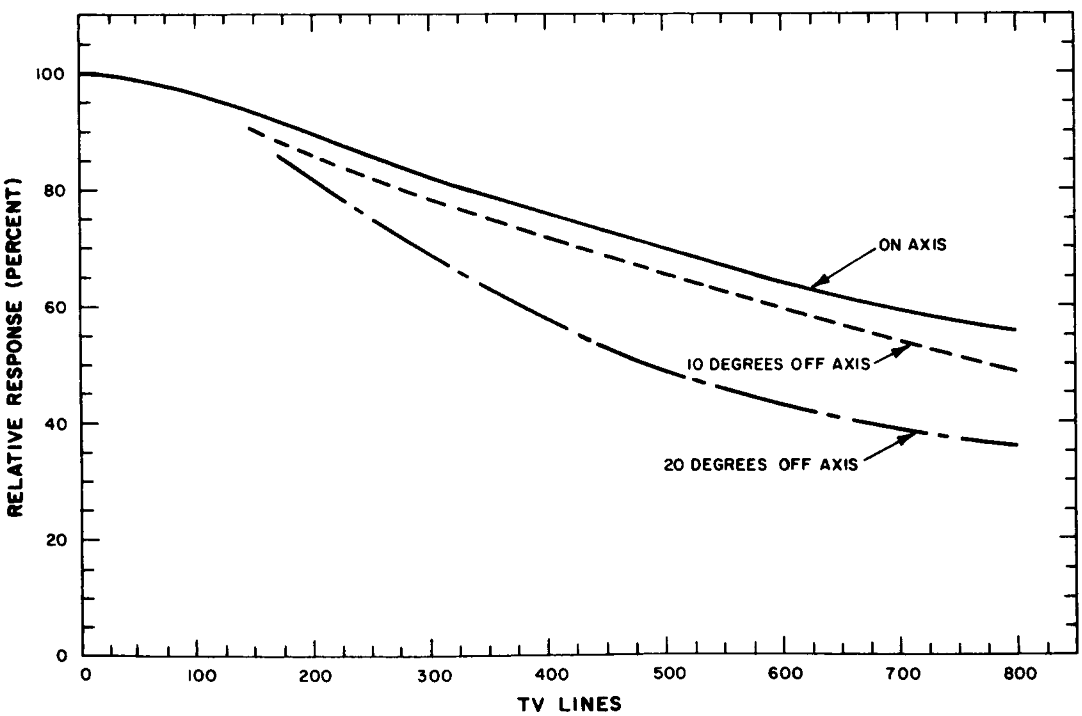


Figure 39. Sinewave Response of Argus 8.1-mm, f/9 Lens No. 0030

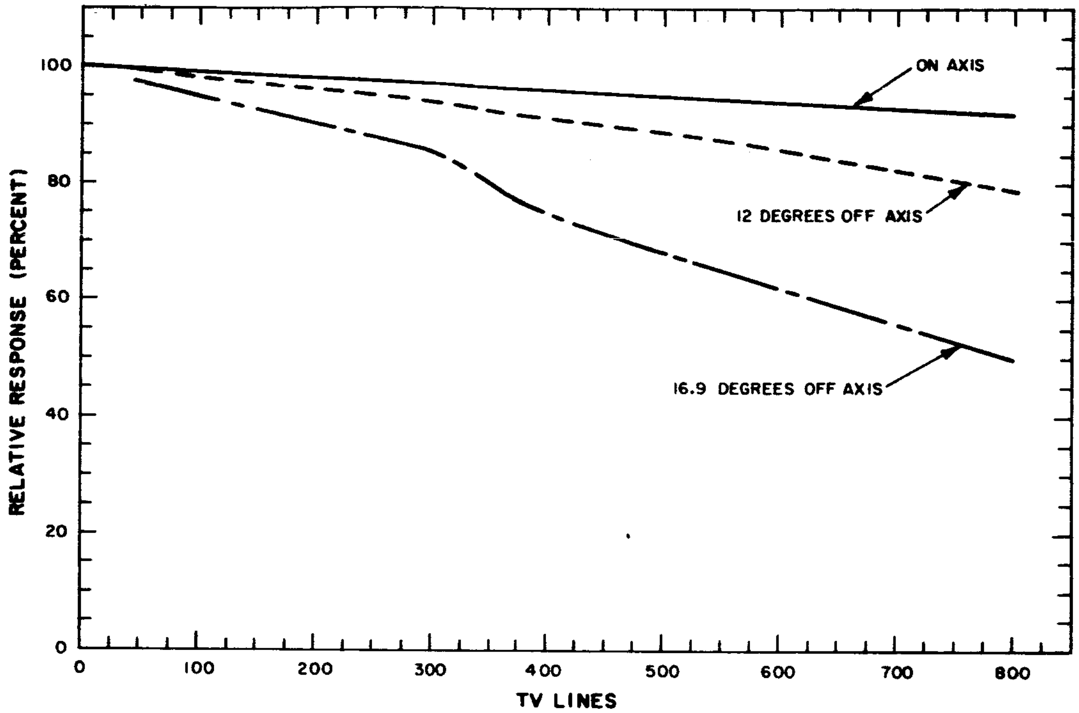


Figure 40. Sinewave Response of Angenieux 25-mm, f/0.9 Lens

D. SCAN CONVERSION

1. System Considerations

a. GENERAL

Scan conversion is, in general, the process of converting from one geometric time domain or pattern to another in the television process. In the space color television system, scan conversion is required to convert the pictures transmitted from space to NTSC color video that meets FCC requirements; i.e., the video output of the ground station must conform to the NTSC color standards in order to allow the use of standard color broadcast equipment to distribute and monitor the space pictures, and feed them directly into a television broadcast network for inclusion in color television programs.

It might appear that the scan-conversion problem could be completely eliminated by designing a space color television system that did not require scan conversion; i.e., to transmit standard broadcast-rate NTSC video directly from the spacecraft. However, there are several reasons for not pursuing this course:

(1) The Doppler effect would create phase errors in the color subcarrier that would have to be corrected, since the uncorrected video signal would not be suitable for direct transmission to home receivers. Therefore, some form of conversion or signal processing would be necessary on the ground, even with NTSC transmission, in missions subject to significant Doppler shift.

(2) For most missions, there are limitations that prohibit the transmission of a 4.5-Mc video signal.

(3) The NTSC video signal is made up of the luminance signal E'_Y and the two chrominance signals E'_I and E'_Q, as defined by the following set of linear simultaneous equations:

$$E'_Y = 0.30\, E'_R + 0.59\, E'_G + 0.11\, E'_B$$

$$E'_I = 0.74\left(E'_R - E'_Y\right) - 0.27\left(E'_B - E'_Y\right)$$

$$E'_Q = 0.48\left(E'_R - E'_Y\right) + 0.41\left(E'_B - E'_Y\right)$$

This arrangement would not permit the correction of any misregistry of the three color signals on the ground. Thus, it can be seen that it is not feasible to transmit an NTSC signal and put it directly on the broadcast network.

There are two general requirements for the scan converter:

(1) It must convert the space-transmitted video to the proper field or frame rate and line rate; and

(2) It must condition the signal to make it conform with NTSC format.

b. IMAGE REGISTRATION

As previously noted, it is desirable to control the registration of the three color images at the ground station, in order to relax the stability and shielding requirements for the space-borne hardware. This method requires the use of three displays at the ground station that can be brought into registry by adjustment of the display size and centering controls. The three displays must be viewed by a camera or set of cameras to convert the images back into electrical signals. The registration of the three images can be made to correct for misregistry contributed by the three spacecraft cameras, the ground display, and the ground cameras.

c. SELECTION OF FRAME RATE

Interlace is used in the standard broadcast frame to take advantage of the particular flicker sensitivities of the human eye. The scan converter is not subject to the same constraints or latitudes. All scan conversion that applies to this study will be used to convert substandard scanning and frame rates to standard broadcast rates; therefore, no advantage is gained by using interlace in the pre-scan-converted signal, with the possible exception of special cases (such as the Hughes/Deutch scheme) where interlace may be useful for image motion fidelity.

It is easier to convert from one frame rate to another if the two rates are related by a whole number; therefore, the space system frame rate should be a submultiple of the broadcast frame rate. This relationship allows the retrace of the read and write beams to occur during vertical blanking. Possible frame rates for the space pictures are 15, 10, 7.5, 6, 5, 3, 2, 1, etc. The actual choice of frame rate is dictated by the available bandwidth and the anticipated rate of motion in the scene to be viewed.

d. SELECTION OF LINE RATE

The preferred line rate (number of lines per frame) for the space pictures is not determined as readily as the frame rate. Of course, the number of lines is, in general, a function of the resolution required for the particular mission.

Another important, but less obvious factor, is the problem of beat (moiré) patterns generated by the spatial frequency interaction of the display raster and the scanning raster of the ground camera. The general rule is that the two scan rates should not be near each other or their harmonics. An exception to this rule is the special case of scan conversion using an all-magnetic system. In this case, the lines per frame should be a submultiple of the broadcast field. The all-magnetic system is not too attractive for space color television because of the registration problem.

e. NTSC COLOR SUBCARRIER CONSIDERATIONS

When considering various schemes for accomplishing scan conversion, the subtle aspects of the NTSC system must be kept in mind. In the NTSC system, the use of a color subcarrier within the luminance bandwidth is feasible because of the line-to-line redundancy in the picture and the fact that the subcarrier harmonics have the spatial effect of cancelling on consecutive lines of the field. If the same frame were to be repeated a number of times, as in the Apollo scan converter for monochrome video, this cancellation effect would not take place. For this reason, the chrominance information would have to be recorded on a separate track or multiplexed on a subcarrier outside the luminance bandwidth. The NTSC composite signal would then be constructed after scan conversion and before transmission.

2. Possible Scan Conversion Systems

a. SYSTEM I SCAN CONVERTER

This system, which fulfills most of the requirements previously discussed, is a variation of the present monochrome scan converter used in the Apollo program. A block diagram of System I is shown in Figure 41; a discussion of its operation follows.

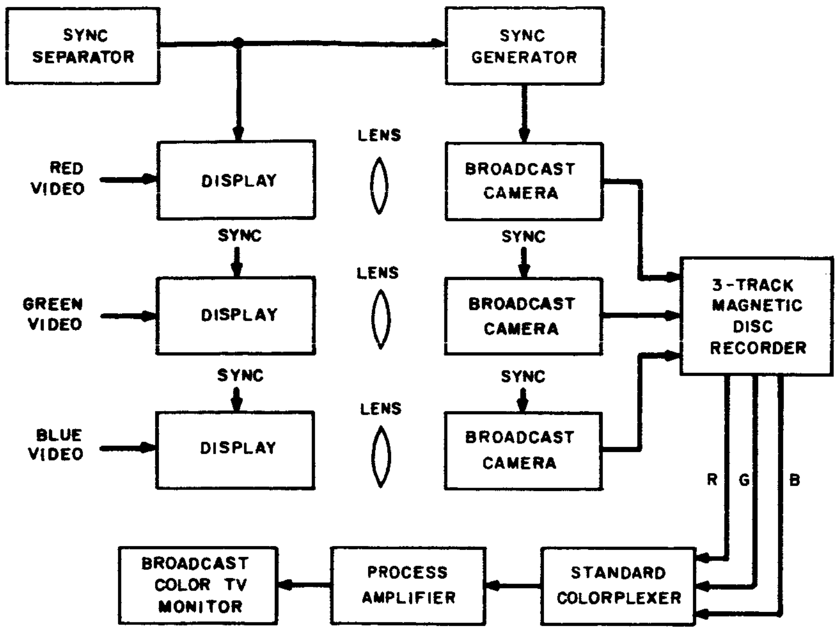


Figure 41. System I, Block Diagram

The demodulated video from the receiver is displayed as three color images (red, green, and blue); or, when a separate luminance signal is used, as four images. The broadcast camera reads out one broadcast frame for each slow-scan frame. This broadcast frame is recorded on the magnetic disc recorder and repeated magnetically until the next slow-scan frame has been stored on the photo surface of the camera tube. The three parallel outputs of the recorder are fed to a standard broadcast colorplexer, since the video at this point has the same form as that from a conventional three-tube color camera.

The primary drawback to this scan conversion scheme is the degradation of the second field by the readout beam of the first field in the broadcast camera. The photoconductive target of the image tube in the camera is exposed as the display beam scans down the frame, causing the image tube to develop a charge pattern that is the analog of the optical image. This charge pattern is read out as two interlaced fields. However, during readout of the first field, the readout beam overlaps and discharges a portion of each line in the second field, because the beam diameter is greater than the space between two lines of a field. Thus, the video signal amplitude of the second field is substantially lower than that of the first field. Another anomalous effect is caused by differences in shading as compared between the two fields. This factor is not yet fully understood. The imbalance between the two fields causes a 30-cycle flicker in the final display when the full frame of video is read out at 60 fields per second. Correction of the field imbalance appears impracticable.

The use of non-interlaced readout was considered as a means of avoiding the problem of field imbalance. This method yields good-quality images, but it has a major disadvantage, since the scan conversion system requires that the same video signal be repeated several times. The noise in a single field repeated several times is much more objectionable to the viewer than noise from two interlaced fields.

The problem of second-field resolution can be solved by using a higher-resolution sensor, which would move the scan lines further apart. Indications are that such a sensor would need a response near 100 percent at a resolution equivalent to the number of scan lines in the frame. A sensor meeting this requirement is the 4.5-inch image orthicon, which has a 2 × 2-inch raster. Recent developments in read gun design indicate that the necessary aperture response may be achieved with the 3-inch image orthicon. The image orthicon has the added advantage of a target with no time constant, which is a source of shading imbalance in the two fields when the vidicon is used. The redistribution characteristic of the image orthicon will also serve to enhance the image.

b. SYSTEM II SCAN CONVERTER

System II, shown in Figure 42, is a variation of System I. In System II, the recorder precedes the display, and by having the read head rotating at a faster rate than the write head, multiples the space frame rate to the field rate of the broadcast camera. From that point on, the video signal is processed in the same manner as that from a conventional three-tube camera.

System II would suffer to some extent from the "repeated noise" problem discussed under System I; however, the effect would not be as pronounced due to the filtering and integrating effect of the broadcast camera.

c. LINE SEQUENTIAL SCAN CONVERTER

This system, shown in Figure 43, can be used to scan convert the line sequential system discussed in Section IIA6. In operation, lines from the red, green, and blue images are displayed sequentially on the respective display tubes. When the three color fields are completed, they are scanned by the cameras. From this point on, operation is similar to that of System I. When used to scan convert the line sequential system of Section IIA6, the converter must eliminate the non-linearities introduced by the use of a different sweep time for green than for red and blue.

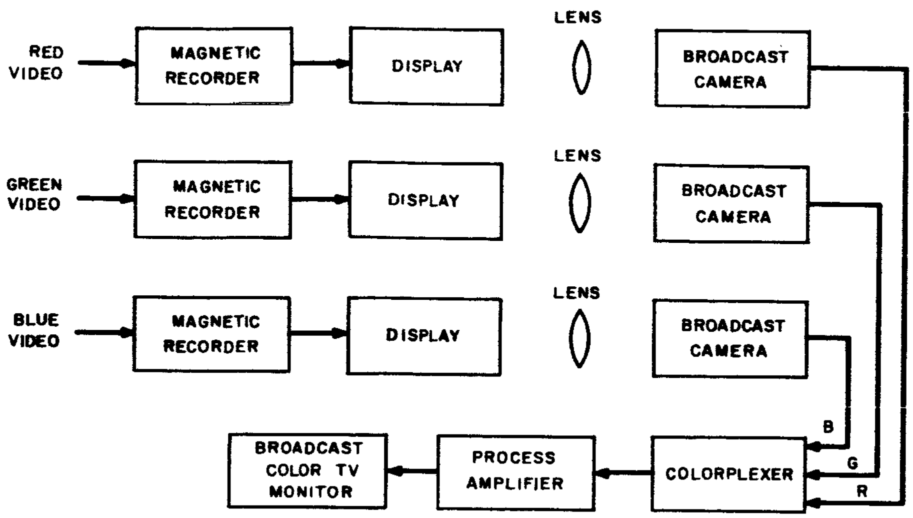


Figure 42. System II, Block Diagram

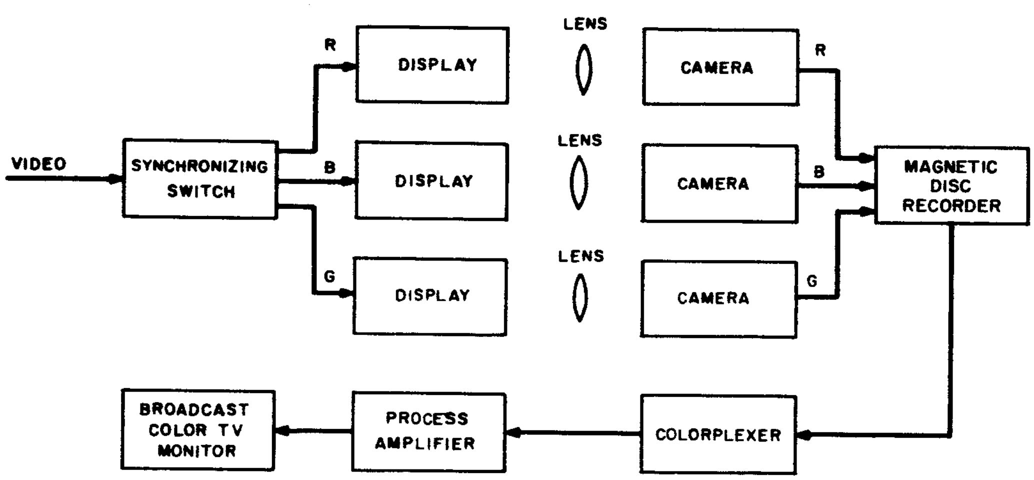


Figure 43. Line (or Field) Sequential Scan Converter, Block Diagram

This system can also be used with a field sequential system. In this application, the complete fields for each color (red, green, and blue) are displayed sequentially. This method presents a more difficult scan conversion problem because the three cameras must store their respective displays during different periods of time. The system could also be built using one display and a rotating prism or shutters to switch from one camera to the next.

d. PHOTOGRAPHIC FILM SCAN CONVERTER

A block diagram for a photographic film scan converter is shown in Figure 44. This system would be essentially flicker-free and would provide consistently good performance over a wide range of line and frame rates. Of course, a film system suffers from the time delay needed for film processing.

e. MAGNETIC SCAN CONVERSION

Magnetic scan conversion is, in general, constrained to applications where the line and frame rates of the slow-scan system are submultiples of the fast scan rate. This constraint limits the slow-scan system to pictures whose resolution is no better than broadcast pictures.

Adapting a standard broadcast type of magnetic recorder to function as a scan converter does not appear to be feasible. However, there are two other tape recorder designs that can be readily adapted to this application; one is a helical type made by Ampex and SONY, and the other is a somewhat similar type designed by RCA Communications System Div. (CSD) for military applications. Of the two, the helical type would probably be favored because of better availability.

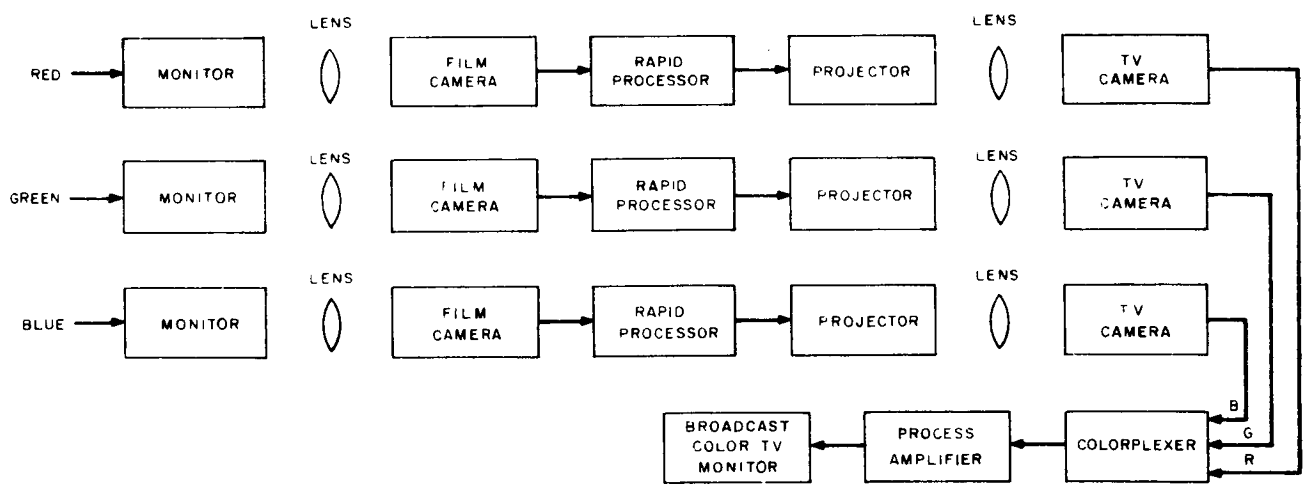


Figure 44. Photographic Film Scan Converter, Block Diagram

A system based on the helical recorders would require two units, one for recording and one for playback. By rotating the playback head an integral number of times faster than the recording head, the signals corresponding to one frame at the input would be repeated the same number of times at the output. The frequency components of the signal would be increased in the same ratio.

A system based on the RCA CSD design would require only one unit, since provisions are included for essentially simultaneous recording and playback. Signals are recorded longitudinally by a stationary head and played back by a rotating head. The speed of the tape and the rotating heads can be separately adjusted to provide an output signal that is an integral multiple of the input signal corresponding to a single frame.

A potential problem in the magnetic-tape conversion methods stems from signal fluctuations caused by slight variations in tape speed. It is assumed, however, that the techniques used to minimize this effect in standard broadcast recorders could also be used to advantage in the proposed system.

f. DIGITAL SCAN CONVERSION

If a television signal is converted from analog to digital form, the picture can be stored in a computer memory. Once stored, the information can be operated upon and read out at any desired data rate (i.e., frame rate, interlace, etc.). The addition of other functions such as vertical aperture equalization is also possible. With more sophisticated computer processing, the number of lines per frame may also be changed.

In applying digital scan conversion to color television, the chrominance signal is best handled as a separate raster in the memory. This, of course, requires greater memory storage capacity. Errors of integration can be corrected in the computer, if auxiliary displays are used to view the three incoming signals.

The speed of the computer process is an important factor. A typical bandwidth for a slow-scan picture is 1.25 Mc. If 6-bit encoding were used for the gray level, the required computer input speed would be approximately 2×10^7 bits per second. Processing of the broadcast-rate picture in the computer would require a computer speed of approximately 4×10^7 bits per second, using separate delta modulators for the Y, I, and Q signals. This capability is within the state-of-the-art for digital data processors, but is pushing the capability limit for general purpose computers.

Computer memory capacity is also an important consideration. Six-bit encoding of one slow-scan (1/7.5 second) frame requires storage of 2.8×10^6 bits per frame. This number would double if the computer program required storage of the next slow-scan frame at the same time. This storage capacity is within the current state-of-the-art.

System cost would be 1 to 2 million dollars, including the computer. Detailed analysis may point out ways to make a special purpose computer that would do the job at considerably less cost.

g. SCAN CONVERSION OF NON-RGB SIGNALS

An NTSC signal can be converted by first reducing the signal to red, green, and blue displays and then proceeding with the conversion, using any of the techniques previously described. Scan conversion of other systems (e.g., PAL or SECAM) that are variations of the basic NTSC principle can also be treated in the same manner. However, the big advantage of being able to correct misregistration at the ground station is forfeited once the color signals are algebraically mixed.

h. SUMMARY OF POSSIBLE SYSTEMS

For the most part, the various scan conversion systems considered entail about the same complexity and appear to have equal potential in achieving the desired conversion of the slow-scan image. The three-channel approach is adaptable to any of the color television systems considered in Section IIA. The magnetic converter is the least versatile. It is quite difficult to cope with a time-shared signal such as the frame or line sequential scan using only magnetic techniques. The digital converter is the most flexible, but it may not be the optimum choice from the standpoint of cost.

In summary, there appears to be no significant technical advantage, from the overall system viewpoint, in selecting one scan conversion scheme over another. Moreover, the type of ground processing and scan conversion used will have no appreciable effect on whatever color system is selected; therefore, the choice of a color system should not be influenced by scan conversion system considerations.

3. Ground Processing Problem

The basic decision to register the color images on the ground has had a major effect on the course of the study. While this technique is sound, as presented in Section IIA, transferring the problem to the ground station has certain repercussions that affect the system. The ground processing of the signal through additional displays, camera systems, magnetic recorders, etc. may introduce degradation, including registration errors (particularly in picture corners), gray-scale distortion, loss of resolution, loss of color fidelity, and a decrease in signal-to-noise ratio.

System registration will be most critical on near-earth missions, where the transmission time to a given ground station is relatively short (perhaps 6 to 10 minutes, which does not leave much time to correct for camera misregistry). However, this problem can be circumvented by communicating with a synchronous communication satellite. Another alternative is to store the incoming signal on magnetic tape and perform registration on playback. These measures may be unnecessary if the registration drift between orbital passes proves to be relatively insignificant. It should be noted, on the positive side, that in cases of poor signal-to-noise ratio of the incoming video, processing through a kinescope-camera chain is used in broadcast studios to improve the pictures' appearance.

The only scan-conversion scheme that is excluded by registration on the ground is the all-magnetic approach. In most of the other scan-conversion techniques, the registration is required anyway because of the kinescope-camera combination.

Although it has not been thoroughly analyzed, the use of a digital computer appears to present the best opportunity for ground processing of the signal, including registration, without significant degradation of the image in the final display. However, there is still the question of the feasibility of using current computers to handle these high data rates.

4. High-Resolution Slow-Scan Processing

As planned, the high-resolution pictures will have equal bandwidth available for red, green, and blue. The frame rate will be approximately one frame per second with a resolution of about 1000 TV lines.

The ground processor should be capable of producing film negatives of maximum fidelity. The best approach appears to be the use of a slow-scan monitor and a film camera to make a black-and-white negative of each color-separation frame. Film pulldown would be accomplished during vertical blanking. After processing, the negatives could be utilized in several ways, as follows:

(1) A study could be made of each color-separation negative to analyze the narrow spectral region that it represents;

(2) The three color-separation negatives could be projected through appropriate color filters, using three separate but registered slide projectors. The resulting color image would be representative of the scene;

(3) A color print (or transparency) could be made by multiple exposure of a color film, using the three color-separation negatives and appropriate color filters. The resulting color pictures could be shown on broadcast television using standard studio equipment for showing color slides.

5. Conclusion

Based on the selection of the variable-line sequential color camera system, the scan converter shown in Figure 43 appears to be the best solution to the near-term problem. This system is a three-channel version of the Apollo Monochrome Scan Converter; the extension of this design to color appears to be straightforward.

SECTION III

COLOR SYSTEM ANALYSIS AND DESCRIPTION

A. GEMINI-AGENA MISSION

The Gemini-Agena mission requires a television-communications system mounted on the Agena to view the Gemini spacecraft during the rendezvous maneuver. The weight and power allocation, based on a previous mission analysis for monochrome television coverage by NASA, is 75 pounds and 100 to 200 watts. The most serious constraint is the time left to implement such a mission. The latest date for having flight hardware available for integration on the vehicle is the end of 1966.

While the mission is feasible, there is good reason to question the allowable schedule. The greatest schedule problem exists in the camera and scan converter area, for there is no existing hardware that could be expected to perform the mission reliably. An analysis of the communication link considerations is given in Section IIB5.

Monochrome television coverage is feasible using essentially existing hardware operating at broadcast rates. However, it does not appear that the monochrome television mission is under serious consideration at this time. Therefore, further effort on this mission analysis has been abandoned with the emphasis placed on similar missions applicable to the Apollo program.

B. APOLLO COMMAND MODULE CAMERA, BLOCK II

The Command Module camera system is based on the following design criteria:

(1) The camera must be compact enought to be hand-held;

(2) The camera must take real-time moving pictures;

(3) The camera system must operate with the existing Apollo communications system with minimum modification;

(4) The pictures must be of broadcast quality, i.e., 300 TV lines per picture height resolution and a signal-to-noise ratio of 34 db; and

(5) When hand-held, the camera must be capable of taking pictures through the window of the command module.

The taking of pictures within the Command Module appears to be limited by the level of ambient illumination and the required size of the camera. (See Section IIC.) A realistic evaluation of the situation leads to the possible conclusion that color television coverage of the Command Module interior may not be worth the effort and technical cost to achieve it. Thus, the use of the camera, within the Command Module, will be limited to taking pictures through the window.

With consideration for the thermal environment, the basic camera should be adaptable for use on the lunar surface or as an externally mounted camera on the spacecraft.

As presented in Section IIC3, the view from the window of the Command Module will be of the earth, moon, possibly another spacecraft, LEM, or astronauts in space. Sources of illumination are the sun, earth, moon, and flashers or floodlights in the case of other spacecraft. With a window transmission of 0.5, highlights will vary from about 6,000 foot-lamberts down to darkness. For an exterior-mounted camera the highlight may reach 12,000 to 13,000 foot-lamberts.

The proposed camera is a 1-inch version of the variable-line sequential color system which was recommended in Section IIA of this report. In addition to the parameters covered in Table 3, the camera has the following characteristics:

Camera Size: 9 × 12 × 3 inches (See Figure 26)

Power at 24 VDC: 8.5 watts

Weight, less lens: 7 to 8 pounds

At f/2 and a highlight of 60 foot-lamberts, the signal-to-noise ratios of the camera are as follows:

Green S/N (peak/rms):	34 db
Red S/N (peak/rms):	40 db
Blue S/N (peak/rms):	40 db

C. LEM LUNAR-SURFACE MISSION

1. Study Approach

The lunar surface application of the color television system can be divided into two modes: motion pictures and high-resolution still pictures. The color motion picture application is similar to the existing monochrome camera application, which is a 320-line, 10-frame-per-second camera. The monochrome camera also has a slow-scan high-resolution mode of 1200 scan lines and 1.6 seconds per frame. The tentative specifications for the Apollo Surveyors Staff call for a high-resolution camera of about 800 to 1000 TV lines resolution.

The dual-mode camera concept has the potential of achieving the two missions with less overall weight than two separate cameras. However, this advantage must be obtained at some compromise in performance and reliability, due to the added circuitry for switching and the fact that two separate systems are in parallel instead of in series from the viewpoint of reliability. In the case of the color camera, the disadvantages of the dual-mode concept are even more pronounced than in the monochrome case and the saving in weight is questionable.

As previously concluded, the motion picture mode requires three image sensors with resolution in the order of 400 TV lines, and the high-resolution mode requires only one image sensor of 1000 TV line resolution. The dual-mode camera, therefore, must use three high-resolution tubes in order to accommodate the high-resolution mission. Review of the possible image sensors shows that the high-resolution image tube is greater in size and power required than image tubes that will satisfy the low-resolution mission. This factor is especially significant when three sensors are required, as shown by Table 29.

From this table of estimated size, power, and weight, it can be seen that the weight saving claimed for dual-mode cameras, though it appears reasonable in this case, is not realizable. It should also be pointed out that the choice of photoconductor for the dual-mode sensors is not optimum for either mode with the exception of the SEC vidicon.

Therefore, it is recommended that two separate cameras be considered for the two modes of the lunar mission: the three-tube low-resolution camera for movies and a single-tube high-resolution camera with switchable filters for the color stills. This arrangement is especially attractive for the Surveyor Staff application where the primary function of the television color camera is to take still pictures. Also, from an operational standpoint, it is probably desirable

TABLE 29. COMPARISON OF CAMERA TYPES

Mode	Camera Type	Sensor Resolution	Weight Less Lens (pounds)	Volume (cu.inches)	Power (watts)
Movie	Three 1-Inch Hybrid Vidicons	600 to 700	8.5	250	10
Dual-Mode	Three 1-Inch Magnetic Vidicons	1000	16.0	350	18
Movie	Three 1/2-Inch Hybrid Vidicons	400	7.0	160	9.5
Slow Scan High Resolution	One 1-Inch Hybrid Vidicon	800	4.2	85	5
	One 1-Inch Magnetic Vidicon	1200	8.0	170	9
Slow Scan High Resolution	One 1-1/2-Inch Hybrid Vidicon	1400	6.0	180	7
Movie	Three 1-Inch Hybrid SEC Vidicons	500	13	540	12
Slow-Scan	One 1-1/2-Inch Hybrid SEC Vidicon	800	7	250	8.5

to have separate motion picture coverage of the "geologist" for surveillance and human engineering data collection. Based on these conclusions, the following separate color television camera systems are proposed.

2. Proposed Camera System

a. MOTION PICTURE CAMERA

The communication link analysis has shown that a 1.25-Mc video bandwidth is feasible, using the existing Apollo-LEM communication system components. Therefore, it is proposed that this bandwidth be utilized for the near-term (next 2 or 3 years) application of color television to the LEM mission.

The proposed operating parameters are identical to the camera system proposed for the Command Module. Physical dimensions would have to be changed by a modest amount to accommodate the lunar environment.

b. STILL PICTURE CAMERA

A one-tube slow-scan frame sequential camera can be designed to operate within any bandwidth (from a few kc to 1.25 Mc) that is consistent with the mode of operation of the camera and the specific mission. Consideration must be given to such factors as:

(1) Cable operation;

(2) R-F link operation;

(3) Stability of camera during frame; and

(4) Use of shutter as well as a filter, if there is a stability problem at low frame rates.

The 1.25-Mc bandwidth will allow a frame time of 2/3 second for a 1000-TV-line resolution picture in a given spectral region.

Erasure of the image is important in the slow-scan high-resolution picture in order to achieve high fidelity of the spectral information in each frame. At a 2/3-second frame rate, manual indexing from one filter to the next allows several frames to be read out between filter changes, and would probably take care of the erasure of the photoconductor. The SEC target erases after one readout frame, making it ideal for the application on this basis. The main drawback to the use of an SEC vidicon appears to be the size of the sensor required to achieve 1000-line resolution. Table 29 illustrates the possible choice of sensors and their size, weight, and power tradeoffs. It appears that the 1.5-inch hybrid vidicon is the optimum choice if the minimum resolution must be at least 1000 TV lines.

The characteristics of the proposed camera system for color stills are as follows:

Bandwidth: 1.25 Mc

Frame Period: 1.6 seconds

Scan Lines Per Frame: 2000

Line Period: 0.8 millisecond

c. OPTICS FOR STILL PICTURE CAMERA

The still picture camera is required to obtain high-resolution photographs of such things as the lunar surface and rock formations; therefore, a relatively narrow-angle lens, focused for pictures two to three feet away, will be required. The lens must have good chromatic correction as well, since only one sensor is used. The detailed design and selection of the optics must be based on more specific mission definition. A typical lens would be the 63-mm f/35 El-Nikkor, which has excellent frequency response and weighs 1/2 pound. This is a commercial lens and would require repackaging for the space environment.

d. OPTICS FOR MOTION PICTURE CAMERA

It is anticipated that the motion picture camera will be used primarily to observe the astronauts on the lunar surface, but will also be used to survey the lunar landscape and take pictures of the earth as seen from the lunar surface. Experience in broadcast television indicated that a zoom lens with a view finder would be the optimum choice for this general purpose use. The zoom lens developed by Argus for Apollo is a good choice; the lens developed by Fairchild for LEM is a suitable alternative. Experience with monochrome cameras on the lunar surface during the earlier mission should provide excellent data for selecting the optimum lens for the color camera.

D. CRITICAL SUBSYSTEMS

1. General

The complete color television system requires development of two areas, the camera and the scan converter. Most of the other subsystems consist of space-qualified components or commercial broadcast equipment that requires only minor modification. The r-f ground equipment either exists or can be manufactured without development. Figures 45 and 46 are block diagrams of the camera and scan converter. The following discussion covers the important aspects to be considered in the design of these subsystems.

2. Camera

As shown in Figure 45, the camera is made up of three similar video channels fed into a common video processing circuit. The green channel differs from the other two in that it has a peaking stage for aperture correction. This type of correction is not required in the red and blue channels because of the narrow spatial bandwidth of these signals as required by the system.

Each channel is clamped and sequentially switched into the video processing amplifier, where clipping and sync insertion is accomplished to make up the composite video waveform shown in Figure 14.

Individual sawtooth generators are required for horizontal deflection; vertical deflection, being common to all three channels, is accomplished by one sawtooth generator with a period of 1/7.5 seconds. Separate vertical drives facilitate independent control of size and centering of each raster.

A common power supply services all three camera chains. A common supply will not create significant crosstalk, since only one channel is generating a signal at a time. This feature is, in fact, one of the attributes of the line sequential system. Based on past experience, it is advisable to lock the power supply frequency to one-half the line rate of the camera. This method requires a somewhat larger transformer but eliminates the problems caused by power supply switching transients getting into the video signal. The required power from a 24 ± 1 volt supply is estimated at 8.5 watts.

The sync generator is also common to all three camera chains, and generates all timing signals (including pulse widths) from a binary countdown circuit. The master oscillator is crystal controlled at 0.983 Mc.

Other circuits not shown in the block diagram are beam current regulators for each tube and cathode blanking.

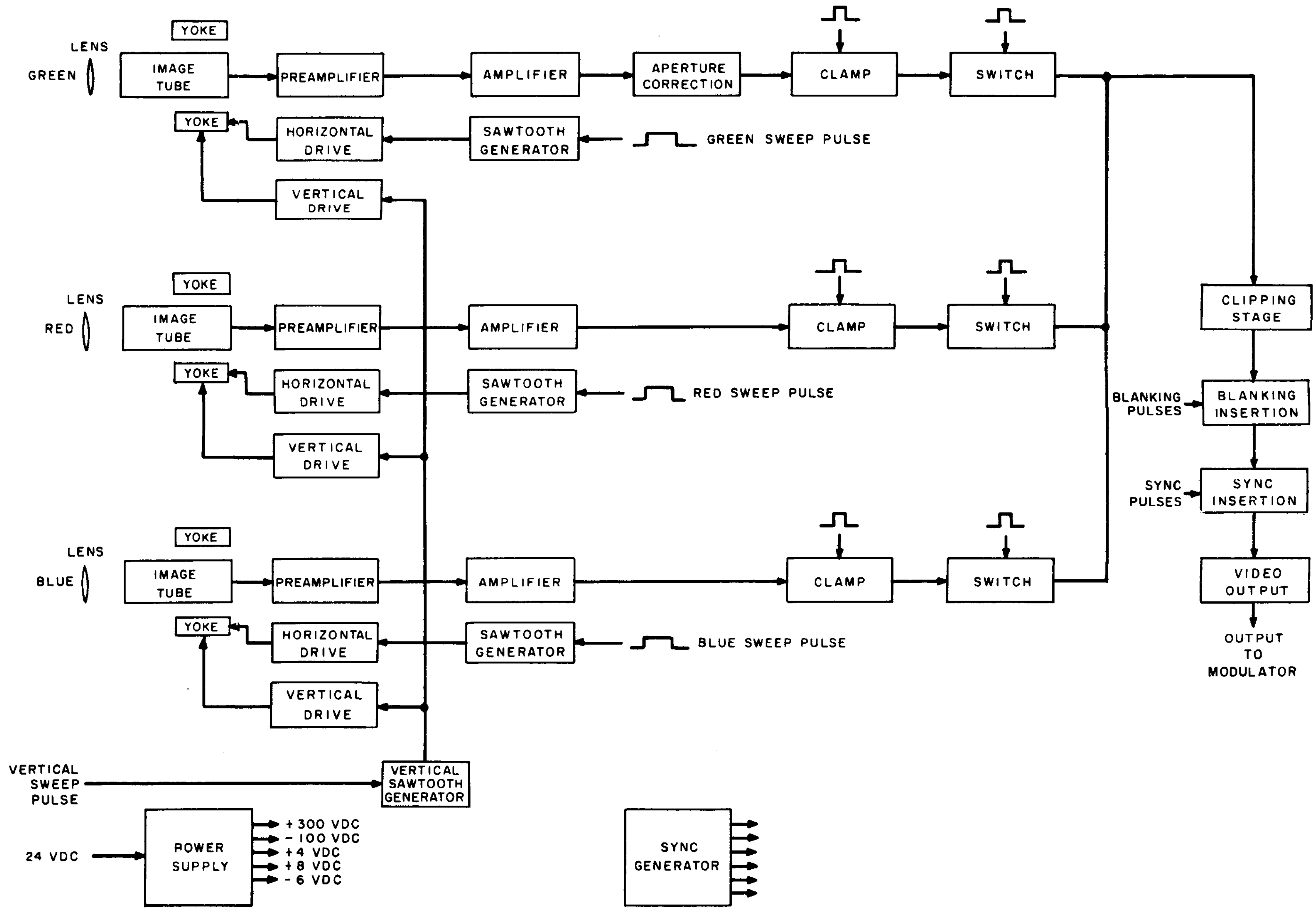


Figure 45. Camera Block Diagram, Line Sequential System

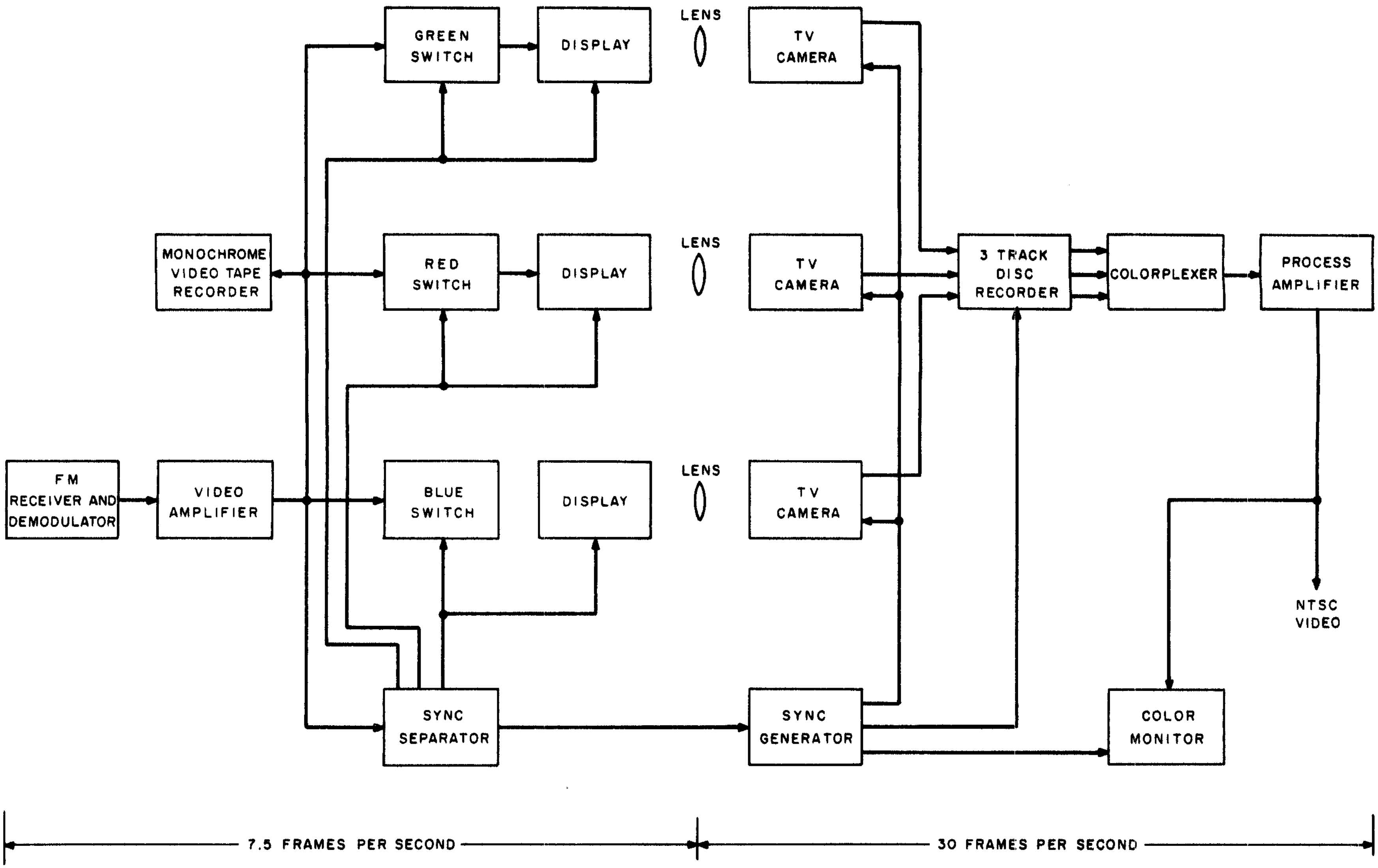


Figure 46. Scan Converter Block Diagram, Line Sequential System

Automatic gain control has not been included because unmatched vidicon target transfer characteristics have a critical effect on the chromatic fidelity of the color system. A modest amount of gain control may be possible by varying the video amplifier gain of all three video chains as a function of the video amplitude of the green chain. Gain control would help in correcting overall ambient light variations.

The basic system may be further improved by controlling the beam current of the sensor as a function of the video signal. This arrangement has been implemented with good results in vidicon cameras used for line broadcast pickup; it helps speed the discharge of gross highlights such as those created by specular reflections, and also allows the quiescent beam current of the sensor to be set lower than normal. This lower setting, in turn, improves the aperture response of the sensor, resulting in less aperture correction and an improvement in the signal-to-noise ratio at high frequency.

It should be noted that all of the sync generator, except the oscillator, and much of the other camera electronics can be designed using integrated circuits. The deflection circuits will be the most difficult to integrate because of the need for very good stability of the scanned raster. The largest subsystem will be the power supply which is estimated at 25 cubic inches. The total camera electronics package should be no larger than about 50 cubic inches.

Shielding the image tube and yoke from external magnetic fields will be an important consideration in the design of the camera. This requirement is complicated by the fact that the three image tubes in the three-prism camera are not parallel, resulting in a different effect on each sensor from an external magnetic field such as the earth's magnetic field. The need for complete isolation is circumvented by the basic system consideration that fine registration of the three images be done in the scan conversion process instead of the camera.

3. Scan Converter

In the block diagram of the scan converter shown in Figure 46, the video signal is demodulated, amplified, and then fed to a wideband video recorder, such as the video recorders used in television broadcast studios. The signal is also fed to a sync separator. The sync separator develops horizontal and vertical synchronizing signals that control all the timing in the scan converter and lock the broadcast section to the incoming vertical frame rate.

As shown in the diagram, the video signal is sequentially switched to the appropriate slow scan monochrome kinescope display, on a line by line basis. At the end of a slow scan frame, three complete pictures have been displayed by the three kinescopes. These images are stored on the targets of the three broadcast cameras. As the write beam of the kinescope nears the end of the frame, the broadcast cameras commence to scan out the stored images. Timing is such that the read beam passes the write beam during vertical blanking. The second field of the broadcast frame is then read out, with the read beam preceding the writing of the next frame.

The broadcast frame is recorded by the three-track disc recorder, which rotates at 3 revolutions per second. The output of the three-track recorder is a continuous video signal, which is updated every fourth frame in the case of the 7.5-second slow scan system.

The disc recorder is a three-track version of the single track machine currently used in the Apollo Monochrome Scan Converter. Multitrack recorders currently under development will fulfill this function.

The three channel video signal is fed to a conventional broadcast colorplexer, which adds the red, green, and blue signals together to make Y, I, and Q signals. These signals are then encoded into the standard NTSC composite video signal.

Registration of the three color images is accomplished by manual adjustment of the size and centering of the scanning raster in each of the broadcast cameras. The registration can also be done by adjustment of the three kinescope displays; however, a TK-41 color camera is proposed for the broadcast color pickup, and this camera already has the facility for registration control.

E. APOLLO APPLICATIONS

The Apollo Applications program has been interpreted for this study to encompass those missions and color television applications that are not considered feasible for the Apollo and LEM programs as currently configured.

1. Apollo Pallet

The Apollo Pallet is one of the Apollo Application missions being studied for extending the basic Apollo mission. The pallet is an area in the Service Module which is attached to the rear of the Command Module. The capability of the pallet has been summarized from North American Report SID-65-266, "Preliminary Design Study of an Experiments Pallet for an Apollo Spacecraft, Final Report."

(1) Experiments weight: 3560 to 3630 pounds;

(2) Experiments volume: 114 cubic feet;

(3) Electrical Power:

  (a) Energy for 3-day mission: 33.9 kilowatt-hours

  (b) Form: 400 cps, 115 volts 3-phase and 25 to 30 volts dc

(4) Thermal Control:

  (a) 70 ± 25°F

  (b) 1600 BTU/hour average for 3-day mission

  (c) 380 BTU/hour average for 10.6-day mission

(5) Data Transmission:

  (a) Earth orbit: 51,200 bits/second

  (b) Lunar orbit: 1600 bits/second

The relatively slow data rate for the onboard communication system means that an auxiliary transmitter would have to be included as a part of the television experiment. A detailed link analysis is included in the North American report.

2. Apollo Pallet Color Television

A Pallet experiment that should be considered is a color television system that could be used to take pictures of the earth or the moon. This system could be used to take pictures of the earth and clouds for meteorological analysis. The information obtained would provide a significant advantage in aiding the safety control of the mission, since up-to-date weather information plays an important part in the selection of the reentry point and splash-down area.

Another application would be to take high ground-resolution color pictures of the earth and sea to demonstrate the feasibility of using a satellite-borne high-resolution color television camera for evaluating natural resources and for oceanography applications.

3. Color Camera for Weather Observation

Cloud cover photographs have proven invaluable on such programs as TIROS and Nimbus. The specifications for the monochrome television cameras used in these programs provide a good reference point in determining the requirements for a color camera for similar applications.

The Nimbus AVCS* camera is a high-quality system consisting of a trimetrogon of three vidicon cameras with 833 active scan lines per camera. These three cameras provide continuous coverage along the orbit with subpoint resolution of approximately one nautical mile. The video is stored in a multitrack tape recorder and transmitted to the ground station once in every orbit.

The nature of the application makes it feasible to consider a frame sequential camera system, shuttered for each frame, since the translation of the vehicle from frame to frame could be easily corrected on the ground. A camera system similar to the existing AVCS camera with the addition of a filter wheel is probably the optimum way to implement this experiment.

Ground processing of the color picture would consist of taking the three black-white-white negatives (representing the red, green, and blue color frames) from the standard Nimbus-AVCS ground station and processing them photographically as discussed in Section IID4. It should be noted that three times as many pictures will have been taken to obtain color. Therefore, the capacity of the tape recorder will have to be increased, or less coverage will be obtained along the orbit.

4. Natural Resources Color Television Camera

a. MISSION CONSIDERATIONS

There is a growing body of evidence that high-resolution, large-area visual photography of the earth from an orbiting spacecraft will provide valuable geophysical data which is available by no other observational technique.

The series of photographs obtained from the recent Gemini 4 and 6 flights provide a demonstration of this potential of visual color photography from space. One of the Gemini 4 photographs shows a series of concentric rings (RICHAT structures) in a particular area of the Mauritanian Mountains. These structures,

*Advanced Vidicon Camera Subsystem

unrecognized prior to the era of space photography, may be the roots of former meteorite impact craters. Entire mountain systems are observable in the Gemini 4 photographs as well as a total view of wrench fault systems. Particularly spectacular in this series of space photographs is the large area view of the oceanic areas in which tonal gradations clearly indicate areas of shallow and deep water. These photographs of the ocean areas would be of great value in any comprehensive analysis of the dynamics of the sea.

The unique attribute of space photography is the synoptic picture is provides of a large area.* This large area coverage provides a continuity of observation which could lead to the discovery of many geologic features which remain undetected by conventional aerial photography. There is an indication that, in the process of creating, by mosaic techniques, the equivalent of the hyperaltitude photographs obtained from the satellite, significant information is permanently lost in the process of adjusting the tonal differences and the overlap regions of the individual small area exposures. Also, mosaics cannot provide stereographic coverage on the extremely small scale of hyperaltitude photographs; and such capability is of extreme importance for geological interpretation.

In addition to its great potential for the field of geological exploration, similar reasoning suggests that satellite visual photography will play an important role in expanding the horizons of topographic mapping, forestry, ice pack reconnaissance, hydrology and oceanography. In the manner that aerial photography was a quantitative breakthrough in many fields (in that the new perspective it afforded permitted recognition of features which might never have been discovered by ground methods), so the available evidence would suggest that visual space photography will provide the next quantum jump in man's capabilities to observe and define the parameters of his geophysical environment.

Now having considered visual space photography and its potential in a generic sense, we must try to define the role of the orbiting television sensor. It would appear that perhaps some unwarranted conclusions have been too hastily drawn on the basis of present TIROS meteorological imagery as to the value of the television sensor in the natural resources application. First, it must be recognized that the dynamic range of the TIROS cameras has been adjusted to properly image the very bright cloud tops, and this dynamic range is not consistent with obtaining good gray-scale rendition on the relatively dark surface of the earth.

*The material in this and the following paragraph is in large part obtained from NASA TN-D-1868, "A Review of Photography of the Earth from Sounding Rockets and Satellites" by Paul D. Lowman, Jr. of NASA.

See also: "Aerial Photography - A Valuable Sensor for the Scientist" by Robert N. Colwell. American Scientist vol. 52, March 1964.

The camera dynamic range must be readjusted specifically for the earth observation mission. Secondly, the resolution currently considered adequate for the meteorological mission (1 to 2 nautical miles) is not consistent with the 25- to 50-foot resolution considered to be a requirement for the resources mission. New television sensors are now available which can provide the 25- to 50-foot resolution on a large area coverage single-frame rendition.

There is probably little question that recovered film from a manned space flight will provide higher-quality visual space photography than the orbiting television sensor with its communication links and subsequent ground data recomposition via display devices. However, there is some concern that manned space flights at 40 to 70 million dollars per launch will not provide the required data density and universal coverage (i.e., polar regions) to firmly establish and fully capitalize on the potential of space visual photography. There appears to be a reasonable basis to assume that the small satellite with its television camera can provide, at a fraction of the cost, a visual space photograph of sufficiently good quality relative to the recovered film to justify its existence as an independent research tool.

As a first step in this program, the Apollo Pallet affords an ideal opportunity to demonstrate what can be done with high-resolution color television in the national resources and oceanographic application.

b. SYSTEM DESCRIPTION

(1) General

For purposes of analysis, this camera systems study is based on an orbital altitude of 300 nautical miles. This altitude is consistent with the Apollo earth-orbit missions and is also typical for the small satellite application, where a significant decrease in this altitude creates stability problems and seriously reduces the life of the satellite.

(2) Sensor Resolution

Figure 47 illustrates the importance of sensor resolving capability in terms of TV lines per inch. The focal length of the lens is directly proportional to the lens aperture for a given lens speed or f-number.

The image diagonal is an important parameter since it is proportional to the ground coverage and also dictates the diameter of the image tube for a given

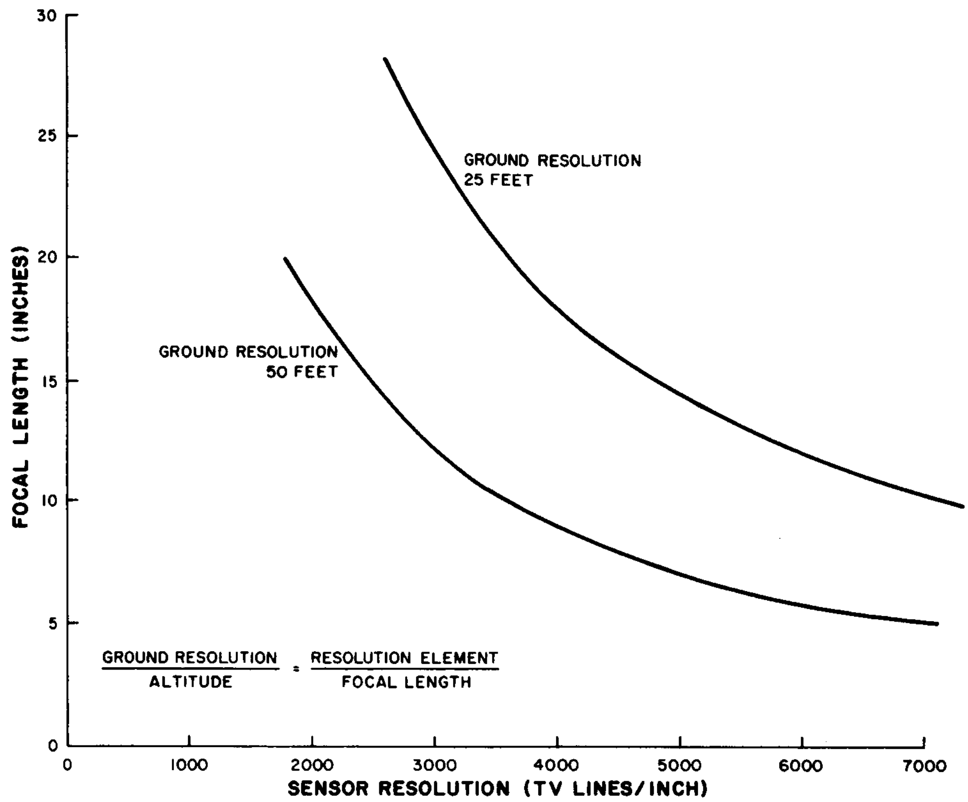


Figure 47. Lens Focal Length versus Sensor Resolution for an Altitude of 300 Nautical Miles

ground resolution and coverage. The tube diameter is in turn roughly proportional to the cube of the power required to deflect and focus the tube's electron gun.

The current state-of-the-art is about 10-percent response at 3200 TV lines per inch center resolution on a one-inch magnetic focus vidicon.

The 4.5-inch return-beam vidicon has also demonstrated 10-percent response at approximately 3400 TV lines per inch. The useful diagonal for the 4.5-inch tube is 2.8 inches or 9500 TV lines.

(3) Ground Resolution Versus Coverage

For a given image format size and sensor resolution, the ground resolution and coverage are related by the equation

$$\frac{\text{Coverage in n.m.}}{\text{Ground Resolution in n.m.}} = \text{TV Lines/Inch} \times \text{Format in Inches}$$

The coverage versus ground resolution for the 4.5-inch vidicon is shown in Figure 48. The ground coverage can be improved over that shown in Figure 48 by using multiple sensors such as the three-camera system used in Nimbus AVCS.

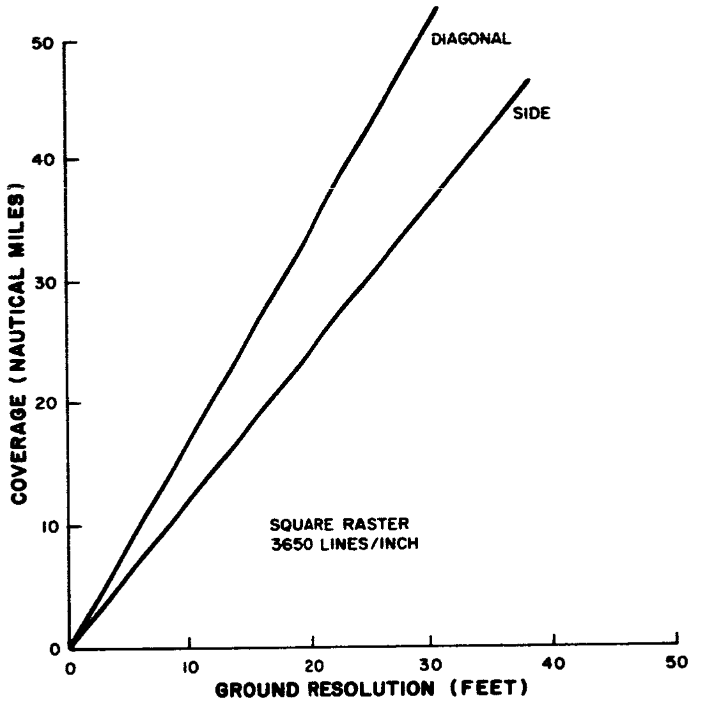


Figure 48. Coverage versus Ground Resolution for the 4.5-Inch Vidicon

(4) Data Rate

The ground speed of the satellite, ground coverage, and ground resolution determine the minimum rate at which data must be recorded or transmitted to provide continuous coverage along the path.

The ground speed is 24,880 feet per second at 300 nautical miles. As an example, let

Path Width	= 30 nautical miles
Ground Speed	= 24,880 feet per second
Ground Resolution	= 25 feet

Thus,

$$\text{No. of resolution elements/second} = \frac{(24,880 \text{ feet/sec})\ (30 \text{ n. m} \times 6080 \text{ feet/n. m})}{(25 \text{ feet})^2}$$

$$= 7,250,000 \text{ resolution elements/second (per spectral channel)}$$

$$= 3 \times 7,250,000 \approx 22,000,000 \text{ resolution elements/second (3-color system)}$$

Including a Kell factor of 0.7 and 5 percent for sync, the readout rate becomes 10,900,000 elements/second or a bandwidth of 5,460,000 cycles/second, monochrome, and 16,380,000 cycles/second for the 3-color system.

Figure 49 shows the variation in required video bandwidth over the range of swath widths from 25 to 100 nautical miles for various values of ground resolution, on a per spectral channel basis.

(5) Smear

The smear in the image due to motion between the camera and the scene is expressed by

$$t\ (wr + v) = \text{Smear}$$

where

t is the exposure time;

w is the angular motion;

r is the distance from camera to scene; and

v is the relative velocity, which is 24,880 feet/per second.

The angular motion can be in the opposite direction to the relative motion; it must then be subtracted from the relative velocity.

The permissible shutter time is directly related to the ground resolution. A 1/2-line smear is equivalent to a 10-percent loss in amplitude response at the limiting resolution. Using 1/2-line smear as the limit, Figure 49 shows the maximum exposure time versus ground resolution, presuming no image motion compensation and no significant angular motion of the satellite (i.e., less then 10^{-3} radian/second).

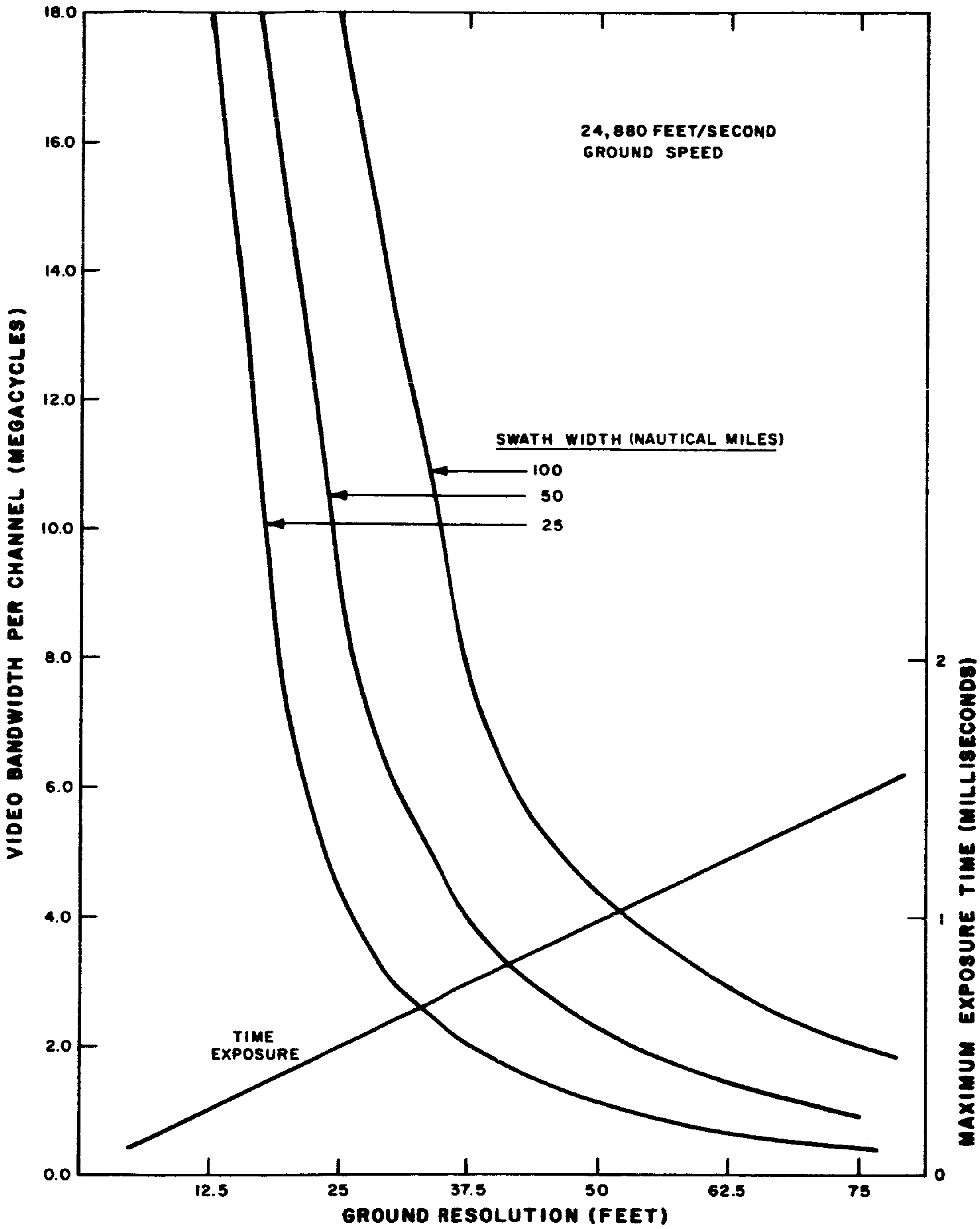


Figure 49. Required Video Bandwidth and Maximum Exposure Time versus Ground Resolution

(6) Sensor Exposure

The exposure of the imaging sensor is given by the equation

$$E_s = \frac{ET\Delta t}{4f^2} \tag{1}$$

where

E_s is the faceplate exposure in foot-candle-seconds;

E is the scene brightness in foot-lamberts;

T is the lens transmission efficiency;

Δt is the exposure time in seconds;

f is the lens f-number, which is equal to $\frac{F}{D}$, where

F is the focal length; and

D is the effective lens aperture.

The scene brightness E is equal to the incident sun illumination which is 13,600 foot-candles times the reflectance of the earth. This reflectance can vary from 0.9 for clouds and ice to 0.2 or 0.3 for the sea and plowed earth. A desirable minimum sensor exposure (E_s) is 0.01 foot-candle-second.

The lens f-number for a typical system may be found by equation 1, using values of

E_s = 0.01 foot-candle-second;

E = 13,600 × 0.02 foot-candles;

T = 0.8; and

$\Delta t = 0.5 \times 10^{-3}$ seconds

Thus,

$$f = \left(\frac{ET\Delta t}{4E_s}\right)^{\frac{1}{2}}$$

$$= \left(\frac{13{,}600 \times 0.02 \times 0.8 \times 0.5 \times 10^{-3}}{4 \times 0.01}\right)^{\frac{1}{2}}$$

$$= 1.6$$

From this basic analysis, the primary system requirements can be formulated. The parameters for two possible configurations are shown in Table 30.

(7) Direct Readout Versus Indirect Readout

The high incoming data rate suggests the use of direct readout and transmission of the data to circumvent the problem of storage. The acquisition time from a single ground station will be approximately 8 minutes. This corresponds to a swath length centered about the ground station of

4 n.m./sec × 60 sec/minute × 8 minutes

or

1920 nautical miles.

The main disadvantage of direct readout, of course, is the fact that a ground station must be located at the site of the desired coverage.

The video information may be stored on video magnetic tape or the image itself may be stored on dielectric tape. Both approaches are feasible. The dielectric tape has the advantage of performing the picturetaking and storage in one device. A magnetic tape recorder would work in conjunction with the vidicon cameras mentioned for the direct readout.

The RCA AMIE tape recorder, developed for satellite application, has a video bandwidth of 6 Mc* and a playing time of 40 minutes. This bandwidth can be increased to 8 Mc with minor redesign. At 8 Mc, the recording time would be about 30 minutes. With this storage capacity, it would take four passes over the ground station to transmit all of the stored data.

The AMIE recorder is packaged in a container which measures 16 × 14 × 8 inches. It weighs 75 pounds and requires 150 watts of electrical power during the record or playback operation.

The transmission of color pictures can be accomplished by using three parallel channels in one transmitter and three subcarriers. The alternative approach is to increase the bandwidth of the video signal by three in order to read out the picture three times as fast. These two approaches are discussed in the communications section of the report, Section IIB7.

*For a 30-db signal-to-noise ratio.

TABLE 30. SYSTEM PARAMETERS

System Parameters Per Spectral Channel	System I 180 n.m. Swath 150-Ft. Resolution	System II 30 n.m. Swath 25-Ft. Resolution
Minimum Data Rate	0.92 Mc	5.5 Mc
Exposure Without Image Motion Compensation	3 ms	0.5 ms
Focal Length	3.3 inch	2.0 inch
(3650 TV lines/inch) (300 n.m. Altitude)		
Image Size, Side	2.0 inch	2.0 inch
F-Number of Lens	4	1.6
Camera Power	75 watts	75 watts
Camera Weight	75 pounds	75 pounds
Recorder Power	120 watts	120 watts
Recorder Weight	100 pounds	100 pounds
Recorder Size	1.2 ft^3	1.2 ft^3

Note: The recorder can be designed for at least two- and possible three-track operation.

c. CONCLUSION

In summary, the Apollo Pallet has the size, weight, and power capabilities that are needed to accommodate the proposed experiment. Implementing the experiment on Apollo would establish the results that may be expected from an unmanned natural resources satellite program.

SECTION IV
OVERALL SYSTEM SUMMARY AND RECOMMENDATIONS

A. MOTION PICTURE TELEVISION SYSTEM

The color television system recommend for taking real-time motion pictures in space comprises the equipment described in the following discussion.

1. Space Components

a. CAMERA

The recommended camera is the three-vidicon, variable-line sequential camera with Phillips dichroic prisms. This camera is shown in Figure 34, a typical block diagram is shown in Figure 41, and performance specifications are found in Section IIIB.

b. SPACECRAFT COMMUNICATION SYSTEM

The existing Apollo-LEM video communication system, including the modulator, is proposed for use in the spacecraft. This system will have to be modified in order to use the entire video bandwidth of 1.25 Mc for television. A detailed description of the communication link appears in Section IIB.

2. Ground Station

a. GROUND COMMUNICATION SYSTEM

The proposed ground communication system for far-earth missions is the MSFN 8.5-Mc receiver and 85-foot dish antenna. For near-earth missions, the 5-Mc Worldwide receiver and 30-foot dish antenna are recommended.

b. GROUND PROCESSING

Ground processing of the line sequential video signal is based on the use of a three-channel version of the Apollo Monochrome Television Scan

Converter. A typical three-channel system is shown in the block diagram of Figure 43.

As discussed in Section IID, there are a number of feasible techniques for scan converting the line sequential signal; therefore, the choice of an optimum scan conversion system cannot be as positive as the selection of the other subsystems considered in this study.

B. STILL PICTURE TELEVISION SYSTEM

The proposed color television system for taking still pictures consists of the space components and ground station equipment described in the following paragraphs.

1. Space Components

a. CAMERA

The recommended camera has a single 1.5-inch hybrid vidicon and a manually rotable filter wheel. At the block diagram level, this camera is similar to the existing Apollo-LEM monochrome camera operating at 1.6 frames per second and 1.25-Mc bandwidth. The camera will require a tripod or equivalent to hold the camera steady, in order to prevent smear in close-up pictures.

b. SPACECRAFT COMMUNICATION SYSTEM

The communication system recommended for still pictures is the same as that recommended for motion pictures; namely, the existing Apollo-LEM video communication system, including the modulator, but modified to use the entire 1.25-Mc bandwidth for television.

2. Ground Station

The proposed ground communication system for still pictures is the MSFN 8.5-Mc receiver and 85-foot dish antenna. Ground processing is based on photographing a high-resolution kinescope and processing the color picture as three color separation negatives. This method is discussed in Section IID4.

C. HIGH-RESOLUTION SNAPSHOT COLOR CAMERA FOR APOLLO APPLICATIONS

The color television system proposed for taking pictures having ultra-high ground resolution consists of the equipment described in the following paragraphs.

1. Space Components

a. CAMERA

The recommended camera has three 4.5-inch vidicons which are exposed simultaneously through a shutter or shutters. The block diagram for the camera is similar to that of Figure 41; camera performance specifications appear in Section IIIE. Recent developments indicate that the same resolution may be achieved with the 2-inch vidicon.

b. SPACECRAFT COMMUNICATION SYSTEM

Development of the spacecraft communication system must proceed concurrently with development of the camera. The proposed system consists of a 20-watt transmitter with a baseband of 6 Mc, and an antenna with a gain of 7 db. Details of the communication system are discussed in Section IIB7.

2. Ground Station

a. GROUND COMMUNICATION SYSTEM

The North American receiver and the 30-foot parabolic antenna are proposed.

b. GROUND PROCESSING

Proposed ground processing consists of storing the video signal on magnetic tape and then displaying the pictures on a high-resolution kinescope, such as the 10-inch Farranti flying-spot tube. The display would then be photographed and processed in the same manner as the lunar surface high-resolution picture. (Refer to Section IID4.)

D. CONCLUSIONS

The study has shown that spaceborne color television is practical and that the variable-line sequential camera is the optimum choice for the near-space mission of obtaining real-time color television pictures. This particular line sequential system has never been demonstrated in the laboratory; therefore, it would be prudent to follow up the study with a laboratory demonstration of the basic system, operating at 7.5 frames per second.

Full evaluation of the system will require scan conversion of the image to allow viewing at broadcast rates. Therefore, it is also recommended that the scan converter be breadboarded in the laboratory. The current development by NASA of a multitrack disc recorder will be of great help in implementing the scan converter.

It should be noted that this laboratory system, with minor modifications, would allow the demonstration of other color system techniques, such as the Y, R, B, the R, G, B, and the quasi-NTSC systems discussed in Section IIA.